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The Bait Shrimp Fishery of Galveston Bay, Texas

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ABSTRACT

From June 1957 through May 1959 the bait shrimp fishery in Galveston Bay, Texas, was studied to determine the species composition and the magnitude of the catch. Total production for the 2-year period amounted to over 676,000 pounds, having a retail value of almost $779,000. The fishery is chiefly in summer and fall; over 90 percent of the production occurred from May through October. Brown shrimp *(Penaeus aztecus)* and white shrimp *(Penaeus setiferus)* were the major species taken. Occurring sporadically were pink shrimp *(Penaeus duorarum)*, seabobs *(Xiphopeneus krφyeri)*, and *Trachypeneus* sp. The median weight of brown shrimp in samples obtained from the fishery was almost static at 2.0 to 4.0 grams and did not exceed 5.0 grams. The median weight of white shrimp fluctuated and ranged up to 15.5 grams. Young white shrimp apparently enter the bay later in the year than brown shrimp, stay longer, and grow to a larger size before leaving for offshore waters. Length-weight relationships for brown and white shrimp were determined.

INTRODUCTION

Several species of commercially important penæid shrimp found in the Gulf of Mexico are commonly used as bait by sport fishermen. The desirability of shrimp for this purpose has given rise to a bait shrimp industry of considerable importance in some areas. De Sylva (1954) found that over 38 million shrimp entered the bait industry on the northeast coast of Florida in 1953. On the west coast of Florida, Woodburn *et al.* (1957) reported almost 59 million shrimp taken for bait in 1955. In a test area in Alabama, Loesch (1957) noted over 17,000 pounds of shrimp taken by bait fishermen in 66 days, and since few of the shrimp were larger than 50 count (50 individuals per pound), this take represents well over 850,000 shrimp. Detailed information concerning the bait shrimp industry in other areas of the Gulf is not readily available. From June 1957 through May 1959 a study was conducted in the Galveston Bay area of Texas to determine the magnitude of the bait shrimp fishery and the size and species of shrimp taken.

Penæid shrimp found along the Texas coast by Gunter (1950) included the white shrimp *(Penæus setiferus)*, the brown shrimp *(Penæus aztecus)*, the pink shrimp *(Penæus duorarum)*, the seabob *(Xiphopeneus krφyeri)*, and *Trachypeneus constrictus*. The life history of the white shrimp has been described by Viosca (1920), Weymouth, Lindner, and Anderson (1933), Burkenroad (1934, 1939), Pearson (1939), and others. Spawning takes place in the open waters of the Gulf from spring to fall. The eggs are demersal and hatch approximately 24 hours after being spawned. The larvæ and post-larvæ are planktonic for about 3 weeks, during which time they move from the saline offshore waters of the spawning grounds to the brackish inshore waters where they adopt a benthic existence. Four to ten weeks of rapid growth are spent in these inside waters. As the shrimp increase in size and mature, they gradually move back to the open waters of the Gulf, presumably to offshore spawning grounds. Less is known about the biology of the other species, but brown and pink shrimp are assumed to have similar life histories.

METHODS

Collection of statistics

A survey in November 1956 revealed about 200 bait stands located on Galveston Bay (Figure 1). In this paper reference to Galveston Bay includes the bay proper, Trinity Bay, East Bay, and West Bay. During the study period about 80 dealers obtained and supplied shrimp for the local bait industry. Bait stands were so widely scattered throughout the area that it was difficult to interview each dealer oftener than every 2 or 3 days and since few maintained records of their catch, much of the information collected was based on their memory and estimates. There are presently few restrictions on bait shrimping activities in the bay, and there was reluctance on the part of some dealers to disclose catch statistics. The production figures obtained, therefore, are considered minimal.

FIGURE 1.—Locations of bait stands in Galveston Bay area.

In order to combine production figures of live and dead bait, it was necessary to determine the weight of a quart of shrimp. Live bait is sold by the pint or quart at $2.00 per quart in summer when shrimp are abundant and $3.00 per quart in winter when they are scarce. On the other hand, dead bait is sold by the pound at 50 to 60 cents per pound. On the basis of 15 samples, 1 quart of live shrimp weighs approximately 1.5 pounds.

Collection of biological samples

Samples of live shrimp were purchased periodically from dealers to determine the size and species composition of shrimp handled. Bait shrimp in Galveston Bay are taken mainly with small otter trawls ranging from 10 to 25 feet along the cork line and upwards of 25 feet in length. Mesh sizes range from 1⅜- to 1¾-inch stretched measure. The gear and methods used by the bait industry are described in greater detail by Inglis and Chin (1959).

Methods of measurement

Several methods of measuring shrimp have been employed. Total length (from tip of rostrum to tip of telson) regarded by Weymouth, Lindner, and Anderson (1933) as the most reliable measure of size of white shrimp is commonly used. Burkenroad (1934), however, suggested that several factors reduced the reliability of total length as a measure of size. He stated that as white shrimp increased in size, the relative length of the rostrum decreased and that white shrimp along the Atlantic coast had a longer rostrum than those in the Gulf of Mexico. Other difficulties with the use of total length were noted by Cole and Mistakidis (1953). It is not uncommon to find the rostrum damaged or partially regenerated. Furthermore, shrimp often assume a flexed position upon preservation and subsequent efforts to measure total length of preserved specimens usually result in separating the head and tail portions.

Most of the preceding objections to total length do not apply to carapace length, a measurement used in some studies. The length of the carapace is generally measured from the lateral base of the eye notch to the median dorsal posterior edge. Carapace measurements require considerable precision since they seldom exceed 65 millimeters in penæid shrimp. Cole and Mistakidis (1953) suggest an accuracy of 0.25 millimeter in their studies on European prawns and shrimps. A further consideration in the use of carapace length is that it may fail to reflect an increase in weight when the latter is caused by increase in girth. Burkenroad (1950) noted that a number of molts after the postmysis stage in *Penæus duorarum* resulted in increase of stoutness rather than length.

By inference, some workers have suggested

the desirability of total weight as a measure of size. Certain disadvantages in the use of total weight are obvious. Material preserved in alcohol or formalin loses weight significantly and the use of balances on board small vessels is difficult. In the present study it was also found to be impractical to weigh shrimp less than 30 millimeters in total length on moderately sensitive balances. Nevertheless, total weight was used for several reasons. We were not subject to any of the limitations noted above; preservation was unnecessary, shrimp were weighed in the laboratory, and few were less than 30 millimeters in length. With the direct-reading balances now available, shrimp can be weighed with great rapidity and accuracy. For example, one person, using a Mettler balance (Type K-7, precision, ± 0.03 gram), measured and recorded the weights of 100 individuals in slightly more than 13 minutes. Several weighings of the same lot of shrimp showed almost identical results. Furthermore, length measurements, when applied to management of most fisheries, require ultimate conversion to appropriate weights and therefore, when practical, measuring directly in terms of weight is preferable to indices based on morphometric relationships.

To convert weights to lengths, length-weight relationships for white and brown shrimp were derived, using the least squares method. Log-log plots of lengths and weights from 976 white shrimp, including 553 females and 423 males, and 802 brown shrimp, including 502 females and 300 males, showed that for both species the relationship was best expressed by the typical length-weight equation:

$$W = aL^b$$

or,

$$\log W = \log a + (b)\ (\log L)$$

where W=total weight in grams, L=total length in millimeters, and a and b are constants.

Length-weight relationships for both sexes were almost identical within each species. Between species, however, brown shrimp are somewhat heavier than white shrimp at comparable lengths. The following equations[1] for each species, males and females combined, are shown graphically in Figure 2:

Brown shrimp:

$$\log W = -5.483 + (3.190)\ (\log L)$$

White shrimp:

$$\log W = -5.289 + (3.075)\ (\log L)$$

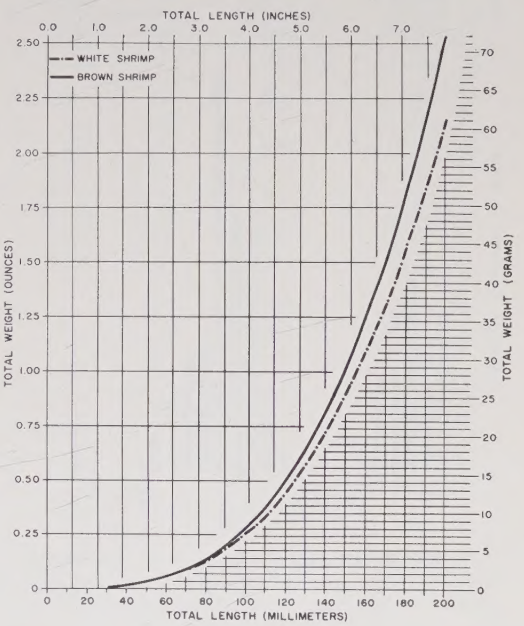

FIGURE 2.—Length-weight relationships for brown and white shrimp.

TOTAL PRODUCTION

Total production of bait shrimp for the 2-year period from June 1957 through May 1959 amounted to over 676,000 pounds with a retail value of almost $779,000. As shown in Figure 3, production was considerably higher during the second year which may have reflected either a greater volume of shrimp handled by the industry or a greater efficiency at collecting statistics. The lower production during the first year, especially in July, was due partially to extensive damage to bait boats and camps caused by hurricanes Audrey and Bertha. Production trends, nevertheless, were similar in both years. In winter there is an apparent scarcity of shrimp in the bay and the fishery is relatively inactive. In

[1]Since these data were obtained, the length-weight relationship for white shrimp has been published by Anderson and Lindner (1958). Mean weights at various lengths shown in their Table 4 were compared to weights at the same lengths calculated using the above equation. Results compare favorably up to a length of 143 millimeters. From 148 to 193 millimeters their mean weights ranged from 1.5 to 6.3 grams higher and at their maximum length listed (198 millimeters) the average weight was 10.7 grams higher than the calculated value. Differences above 148 millimeters may be due to differences in degree of maturity.

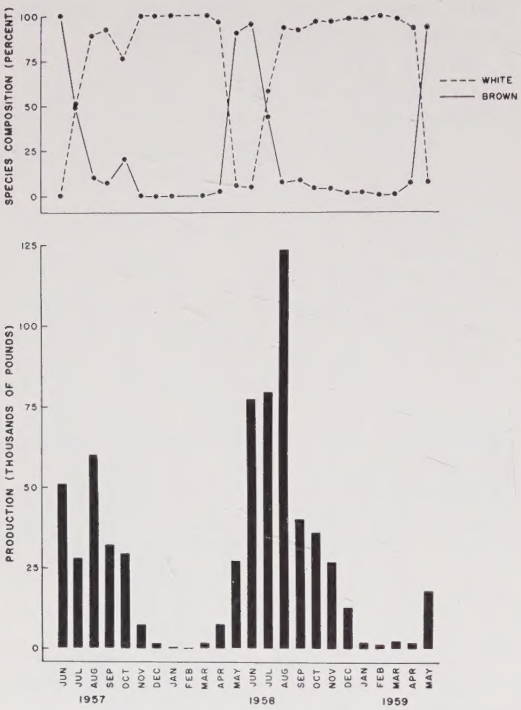

FIGURE 3.—Monthly production of bait shrimp in Galveston Bay area and percentage species composition by weight. Minor species not shown.

spring the bait catch begins to increase and in May rises sharply when the young of the year are recruited into the fishery. Production reaches a peak in August and thereafter declines rapidly until November when it is 15 to 20 percent of the August catch.

Practically the entire catch was obtained within Galveston Bay. In the winter shrimp are occasionally brought in from other areas in ærated tank trucks. During the winter of 1957-1958 less than 5,000 pounds were transported from the Sabine area, about 60 miles to the east. The following winter approximately 2,000 pounds were brought in from the same area and almost 1,400 pounds from the Port Aransas area, about 200 miles to the south.

A comparison of shrimp production by the bait fishery with that by the commercial fishery[2] in Galveston Bay is shown in Table 1. Data on the commercial fishery were obtained from the monthly summaries of shrimp statistics collected by the U. S. Bureau of Commercial Fisheries and available, thus far, through April 1959. Commercial production trends were necessarily affected by state regulations in force during the study. The bay was closed to commercial fishing from December 15 to March 1 and from July 15 to August 31. The bait fishery, on the other hand, is not subjected to any seasonal limitations.

During winter when the bait fishery was inactive, the commercial fishery was restricted by regulations. Unlike the bait catch which rose in May, the commercial catch was almost non-existent during spring even though the bay was opened to commercial trawling. As shown by Figure 4, this difference was probably due to the preponderance of young shrimp too small for the commercial fishery but suitable for the bait fishery. During the study there was no minimum size limit in Texas for shrimp used as bait. For commercial purposes the minimum size limit was in terms of no more than 39 shrimp per pound. From July 15 to August 31 the bay was again closed to commercial fishing; thus, through a combination of circumstances the bait catch from May through August was considerably greater than the commercial catch.

The commercial catch first assumes sizeable proportions in August. The regulations for the commercial fishery are interpreted locally as permitting fishing on August 31 and the catch landed on the last day of August in each year was approximately 80 percent by weight of the bait catch for the entire month. From September through November in 1957 and through December in 1958, production by the commercial fishery far exceeded that by the bait fishery.

SPECIES AND SIZE COMPOSITION

Only a few samples of the relatively small amount of shrimp transported from other areas were obtained and the data are not included in this report. The following discussion is limited to the species and size composition of local shrimp entering the bait industry. During the 2-year study 170 samples containing a total of 16,224 shrimp were examined. If the samples are assumed to be representative of the populations of shrimp in the bay, that is, within the limitations of gear selection, the seasonal occurrence and sizes of the various species can be compared.

[2]In spite of the obvious commercial aspects involved, the bait fishery is considered apart from the commercial fishery which catches shrimp for use as food.

TABLE 1.—*Shrimp production by bait and commercial fisheries in Galveston Bay, 1957-1959*

[Shrimp transported from other areas omitted.]

Month	Live bait		Dead bait		Total bait catch		Commercial catch
	Pounds[1]	Retail value	Pounds	Retail value	Pounds	Retail value	Pounds
June 1957	41,221	$54,962	9,850	$ 5,275	51,071	$60,237	(none)
July	22,391	29,854	5,667	3,161	28,058	33,015	(none)
August	37,790	50,386	22,417	11,208	60,207	61,594	46,730
September	21,915	29,220	10,465	6,059	32,380	35,279	533,875
October	22,785	30,380	6,913	3,563	29,698	33,943	160,636
November	4,910	6,540	2,528	1,164	7,438	7,704	1,453
December	1,260	1,680	251	125	1,511	1,805	(none)
January 1958	324	648	(none)	—	324	648	(none)
February	120	40	(none)	—	120	40	(none)
March	1,193	2,255	428	215	1,621	2,470	(none)
April	6,086	7,542	1,483	841	7,569	8,383	(none)
May	23,850	36,998	3,494	1,746	27,344	38,744	(none)
June	64,397	94,083	13,149	6,573	77,546	100,656	(none)
July	63,791	96,188	15,385	8,774	79,176	104,962	(none)
August	53,817	81,236	69,627	40,595	123,444	121,831	99,616
September	18,305	24,406	21,758	11,608	40,063	36,014	422,735
October	22,101	29,468	13,949	7,142	36,050	36,610	163,276
November	20,574	27,432	6,049	3,092	26,623	30,524	73,374
December	10,832	14,442	1,838	919	12,670	15,361	33,257
January 1959	1,819	3,639	(none)	—	1,819	3,639	(none)
February	1,077	2,154	(none)	—	1,077	2,154	(none)
March	2,424	4,848	(none)	—	2,424	4,848	(none)
April	1,633	3,267	150	90	1,783	3,357	2,305
May	16,380	21,852	1,223	611	17,603	22,463	——[2]
Totals	460,995	$653,520	206,624	$112,761	667,619	$766,281	——

[1]Converted from quarts by multiplying number of quarts by 1.5.
[2]Information not yet available.

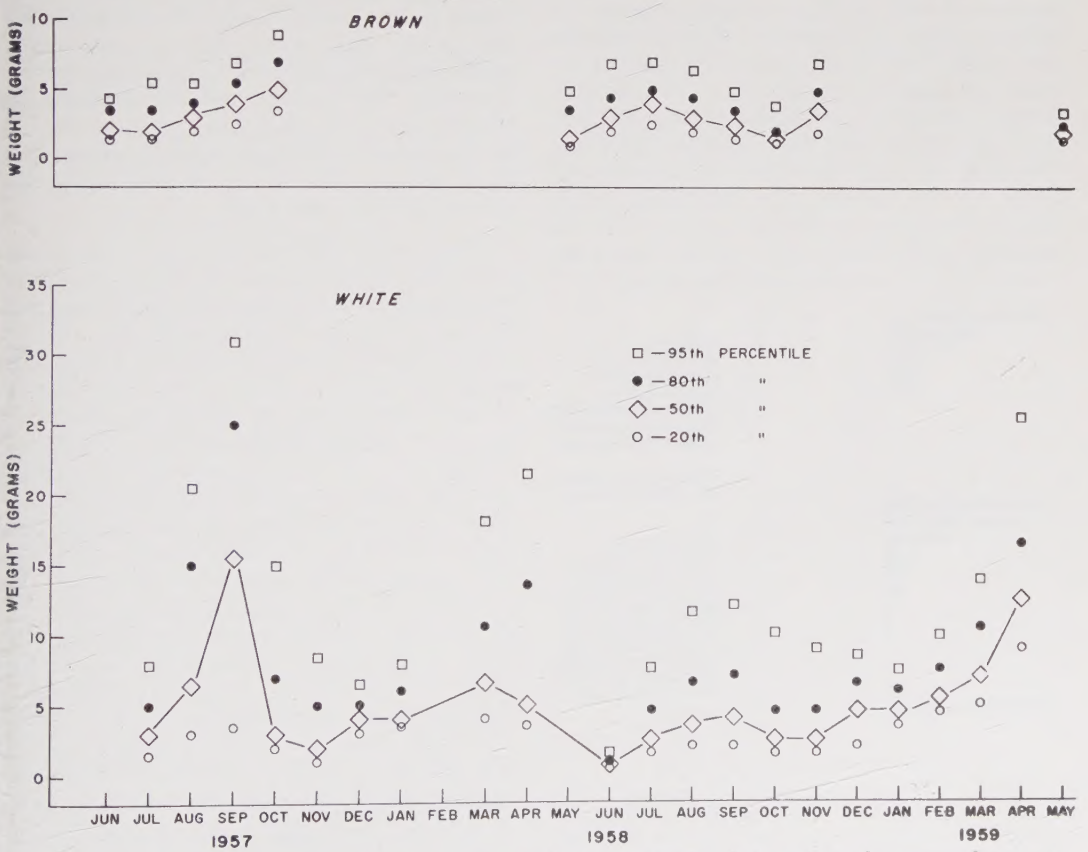

FIGURE 4.—Monthly changes in size composition of brown and white shrimp shown by percentiles.

Pink shrimp *(P. duorarum)*, seabobs *(X. krφyeri)*, and *Trachypeneus* sp. appeared sporadically in the samples. Pink shrimp, ranging from 1.0 to 13.9 grams, made up 9 percent of the samples in October 1957 and less than 1 percent in January and May 1958. Seabobs, ranging from 1.4 to 3.3 grams, amounted to less than 1 percent of the shrimp in July 1957 and in December 1958. *Trachypeneus* sp., ranging from 1.1 to 7.5 grams, formed 1 to 2 percent of the samples in December 1958 and February and March 1959.

Brown shrimp *(P. aztecus)* and white shrimp *(P. setiferus)* are the principal species supporting the local bait industry. Figures 3 and 5 show monthly changes in the percentage of each of the two species by weight and by number, respectively. *P. aztecus* seems to be important only from May through July. In May and June it is virtually the sole species supporting the bait industry. In July the catch is composed of brown and white shrimp in approximately equal proportions. In August, the peak month of production, about 90 percent of the catch by weight consists of white shrimp. During the following months the rapidly declining catch continues to be made up almost entirely of white shrimp. Brown shrimp do not again appear in numbers until April and May when the incoming young of the year give rise to increased activity by the fishery. Concomitantly, white shrimp disappear from the bay and do not reappear in the catch until June or July when a new crop is recruited into the fishery.

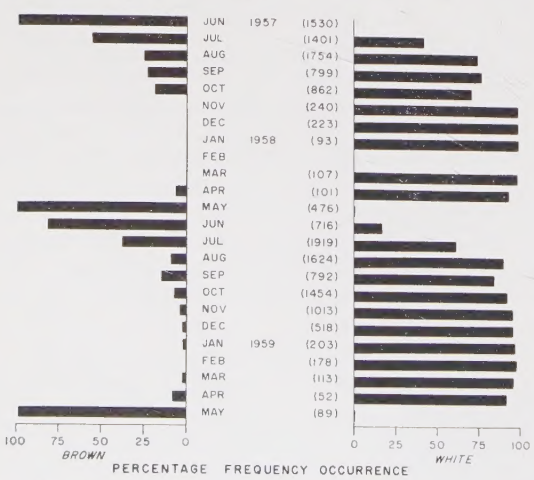

FIGURE 5.—Monthly changes in percentage frequency occurrence of brown and white shrimp obtained from Galveston Bay area. Figures in parentheses denote number of shrimp in samples.

The sizes of the two species differed markedly; brown shrimp ranged up to 23.5 grams, while white shrimp ranged up to 40.7 grams. The weight frequencies of shrimp in the samples were grouped by half-gram intervals so that resulting midpoints at 0.5, 1.0, 1.5 grams, etc., included shrimp that weighed 0.3 to 0.7 grams, 0.8 to 1.2 grams, 1.3 to 1.7 grams, etc. Figure 4 shows the 20th, 50th (median), 80th, and 95th percentiles of the weights of each species for each month. The data are not shown for months when the frequency occurrence of a species was 10 or less.

The median weight for brown shrimp was almost static at 2.0 to 4.0 grams and did not exceed 5.0 grams; the 95th percentile did not exceed 9.0 grams. Median weight for white shrimp fluctuated considerably more and reached 15.5 grams, and the 95th percentile ranged to 31.0 grams. The recurring abundance of shrimp less than 5.0 grams indicates that both species have an extensive spawning season. Changes in size and species composition are sufficiently consistent to show that young brown shrimp enter the estuarine waters earlier than white shrimp, presumably as the result of an earlier spawning season. Assuming that the two species have similar growth rates, the white shrimp must stay in the inshore waters longer since it grows to a larger size than the brown shrimp before disappearing from the bay.

These major differences in life history between the two species may be factors that have contributed to the decline of white shrimp and increase of brown shrimp over the past 20 years. Since the brown shrimp spends less time inside the bays, it is not as heavily exposed to the fishing effort of the bait industry as the white shrimp. Furthermore, by virtue of a short stay in the bay, the brown shrimp does not reach a commercially desirable size until it leaves the bay. In fact, the highest value of the 95th percentile for brown shrimp (9.0 grams) falls somewhat short of the minimum legal commercial size count of 39 shrimp per pound, which is equivalent to about 11.5 grams per shrimp. In contrast, the white shrimp reaches a commercially desirable size while inside the bay. In 9 of the 20 months in which white shrimp occurred more than 10 times in the samples, the 95th percentile was greater than the minimum legal commercial size. The white shrimp is thus subjected to exploitation by the commercial

fishery while in the bays, a fact which is strikingly demonstrated by the species composition of the commercial catch. Except for 664 pounds of brown shrimp caught in September 1957, the entire commercial catch from Galveston Bay shown in Table 1 consisted of white shrimp.

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Comparative Evaluation of Two Tilapias as Pondfishes in Alabama

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ABSTRACT

The Java tilapia, *Tilapia mossambica*, is a very efficient pondfish. Total production in ponds stocked with brood fish varied with different rates of feeding from 1,477.1 pounds per acre in 168 days to 4,383.9 pounds per acre in 191 days. Total production varied from 771.1 pounds per acre in 123 days in ponds stocked with 4,000 fingerlings to 2,945.7 pounds per acre in 111 days in those stocked with 20,000 fingerlings. The Nile tilapia, *Tilapia nilotica*, in limited tests with feeding, yielded a maximum of 4,003.7 pounds per acre in 208 days with adult stocking and 2,380 pounds per acre in 113 days with a stocking of 16,000 fingerlings. Combinations of largemouth bass, *Micropterus salmoides*, and the Java tilapia produced a higher percentage of harvestable-sized tilapia (6 inches or more) and a smaller total production than tilapia used alone. Highest production of harvestable fish was obtained by delaying stocking of bass until August, when many tilapias were too large to be eaten. Tilapias spawned when stocked into established bass-bluegill populations, but very few young survived. Tilapias hatched late in April or early in May reached sizes from 6 to 8 inches within 3 months when adequately fed. The channel catfish, *Ictalurus punctatus*, the Java tilapia, and the Nile tilapia were almost equally efficient in food conversion and were superior to common carp, *Cyprinus carpio*, and the speckled bullhead, *Ictalurus nebulosus marmoratus*. Maximum productions of harvestable fish per acre during one growing season in Alabama were 2,453.1 pounds with the Java tilapia, 2,233.6 pounds for the Nile tilapia, and 2,363 pounds for the channel catfish within 191 days, 113 days, and 252 days, respectively. Increasing rates of stocking of fingerling tilapias decreased rates of reproduction, indicating possible presence of a repressive factor affecting reproduction. The Nile tilapia appeared to be more readily affected and populations of this species contained a higher percentage of harvestable-sized fish than the Java tilapia. Ponds stocked with brood tilapias April 15 to 20, were opened to fishing the following August. The maximum catch per acre was 593.6 pounds in 1957 and 590.6 pounds in 1958 in ponds stocked with the Java tilapia. The Nile tilapia grew to larger size but were less readily caught by fishermen. The catch of this species was only 128 pounds in a pond containing 1,621 pounds of harvestable tilapia per acre.

INTRODUCTION

One of the most spectacular developments in fresh-water fisheries within the past quarter century has been the rise of a cichlid, *Tilapia mossambica*, to major importance as a pondfish throughout much of the world. This fish was first used in pond culture in Java in 1938 and 1939. Under Japanese occcupation during the past war, this species was transported into Thailand, Burma, Malacca, and Sumatra to replace the Asiatic carps that could no longer be imported from China during that period (Hofstede and Botke, 1950). Results were so encouraging in these areas that this tilapia was widely hailed as the wonder fish that could supply much of Asia's protein deficiency. In subsequent years it was introduced into the Philippines, Formosa, Ceylon, Malaya, British West Indies, Trinidad, India, Borneo, Pakistan, Puerto Rico, Hawaii, the United States proper, and elsewhere (Chen, 1953; Atz, 1954).

While the common carp, *Cyprinus carpio*, must still be considered the foremost pondfish in worldwide culture, the Java tilapia bids fair to usurp this position in tropical countries. The qualities that have made it popular are the ease with which it can be cultured, the high production it can yield under proper conditions, and its rapidity of growth. A pond stocked with this species will yield a crop with no further attention; and, as the fish farmer learns to improve his cultural practices, production increases proportionally. Annual production per acre obtained with the Java tilapia varied from a low of 270 pounds per acre in rice fields in Taiwan (Chen, 1953) to a high of 6 to 8 tons per acre with heavy fertilization and very heavy feeding in Thailand (Pongsuwana, 1956). Chen (1953) reported that, without feeding, the average annual production per acre in Java was 292 pounds; with fertilization or feeding, it was 1,065 to 2,500 pounds in Malaya and 2,937 pounds per acre in Taiwan. Chimits (1957) reported production of 5,600 pounds per acre in sewage ponds in Indonesia.

The Java tilapia is a mouthbreeder, producing 100 to 300 or more young fish per female per hatch. Females may produce successive broods at intervals of 30 to 40 days in tropical areas. The young fish feed upon crustacea and unicellular algae, while older fish feed upon filamentous algae and decaying organic matter (Vaas and Hofstede, 1952). The adults reach weights of 5 pounds or more in tropical countries.

While this species of tilapia has won wide acceptance as a pondfish, it has not met with unqualified approval. It reproduces so vigorously that most of the fish produced in ponds often are too small to be acceptable for use in most countries; and also, because it can live in salt water as well as fresh water, it became a competitor with the more valuable milkfish *(Chanos chanos)* in Philippine ponds (Chimits, 1957).

On January 4, 1954, a shipment of *Tilapia mossambica* was received by the author from Earl S. Herald, Steinhart Aquarium, San Francisco. These fish were disinfected, kept in aquaria for 3 to 5 months, and examined to be sure that they did not harbor parasites or diseases before they were stocked in experimental ponds.

Tests at Auburn in aquaria in a cold room indicated that the Java tilapia ceased feeding at temperatures below 60° F. and died at 48° F. (Kelly, 1957); Chimits (1957) gives the death point at 8° C. (46.4° F.). It was therefore evident that this species could not survive average winters outdoors in the Southeast north of central Florida. Consequently, it appeared perfectly safe to use this species widely in various experiments without danger of its becoming a nuisance species.

In a preliminary report production in Alabama of 3,224 pounds tilapia per acre in a 169-day period and use of the species to control the filamentous alga *Pithophora sp.* was noted (Swingle, 1958). In comparable experiments the Java tilapia yielded approximately three times the production of bluegills *(Lepomis macrochirus)* with dry feeds, 1.7 times the yield with inorganic fertilization, and two times the yield with stable manure (Kelly, 1957). It was thus evident that this tilapia was a relatively efficient species as would be expected from its herbivorous feeding habits.

The experiments reported herein were conducted from 1956 to 1959 to measure the annual production and relative efficiency of the Java tilapia as compared with American pondfishes, and to devise methods for its management as a commercial and a sport fish. The Nile tilapia, *Tilapia nilotica*, was brought to Auburn by S. Tal from Israel in 1957 and experiments with this species are included in this report.

EXPERIMENTAL PROCEDURES

The brood tilapias were overwintered in feeding troughs in a heated building. After pond waters had warmed above 60° F. and further severe cold spells appeared unlikely, the brood fish (3 to 6 inches long) were stocked between April 15 and May 1 in hatchery ponds and production experiments. The first spawning occurred the last part of April or the first part of May. Fingerling fish for stocking were raised to a size of 2 to 3 inches and were planted in experiments from June 15 to July 21.

All ponds were fertilized at standard rates with inorganic fertilizers. The feed used was the Auburn No. 1 or No. 2 fish feed in the form of pellets three-eighths inch in diameter and approximately 1 inch long (Swingle, 1957b, 1959). Pellets were broadcast once daily, 6 days weekly, in water 1 to 3 feet deep along one side of a pond on one day and the opposite side on the next day.

Ponds were drained in late October or early November before cold weather killed the fish; and all fish were separated into species and inch-groups, and weighed. All tilapia in the 6-inch group and larger were counted. Those fish in the 1- to 5-inch groups were subsampled and the total numbers calculated. Total production was calculated by subtracting the weight of fish stocked from the total weight recovered on draining of the pond.

The A_T value, or percentage by weight of harvestable fish in a population, was calculated using the 6-inch group for tilapias and the 10-inch group for largemouth bass as the minimum harvestable sizes (Swingle, 1950). Since feeding was of a supplemental nature and the fish obtained some natural feeds in the pond, efficiency of feeding was calculated as the *S* conversion value (Swingle, 1959). This value was obtained by dividing the total pounds of pellets fed by the total pounds of

fish produced. No corrections were applied for the production that might have been obtained without feeding, since accurate corrective values for a wide variety of conditions are very difficult to obtain under the conditions of supplemental feeding in ponds. It was suggested by Swingle (1959) that *C* be used to express conversions only where fish had access to no other feed except that being fed (as in feeding troughs) or where accurate corrections had been made for growth resulting from the additional feeds available. It is therefore possible to calculate the *S* conversion value and from it to estimate the *C* value when additional information is available.

The gain in pounds per acre per day was calculated by dividing the net production in pounds of fish by the number of days in an experiment. The growing period for tilapias was while water temperatures remained above 60° F. In Alabama this period extends from approximately May 1 to October 1, or 5 months in average years.

PRODUCTION IN PONDS STOCKED WITH BROOD TILAPIAS

Total annual yields of 2,000 to 4,000 pounds of fish per acre in ponds have long been reported from tropical areas of Asiatic countries (Lin, 1949). This production was in striking contrast to the 100 to 600 pounds per acre yielded by ponds in the United States. High Asiatic production was obtained, however, by heavy supplemental feeding, which was not practiced in American ponds in past years. In addition, a tropical climate provides a year-round maximum growing season for fish, while the growing period for fishes in the United States varies from 5 to 8 months, including a shorter period for maximum growth.

It is thus of interest to compare production of tilapias in ponds at Auburn, Alabama, with productions obtained in Asiatic countries. The results of production tests at Auburn with various rates of stocking and feeding are given in Table 1. Without feeding, fertilized ponds produced 347.4 pounds per acre in 187 days when tilapia were subjected to bass predation in Pond S-858, and 1,477.1 pounds per acre within 168 days where tilapia were raised alone (Pond F-356). In contrast, annual production in unfertilized ponds was 270 pounds per acre in Formosa, 292 pounds per acre in Java, and 1,065 to 2,500 pounds per acre in fertilized ponds in Malaya (Chen, 1953).

Highest production was obtained with fertilization plus feeding (Table 1). When tilapias were raised alone, total net production varied from 1,765 pounds per acre in 154 days in Pond F-1358 to 4,198.4 pounds per acre in 196 days in Pond S-1158; the lower production resulted from feeding 1,322 pounds, and the higher from 4,030 pounds of the pelleted feed. When recalculated on the basis of a growing period of 365 days, 4,198.4 pounds in 196 days would be equivalent to an annual production of 7,809 pounds per acre.

This calculated production for Alabama is far below the maximum yield of 16,465 pounds per acre per year reported by Pongsuwana (1956) in tropical waters of Thailand. He also reported a second experiment in the same pond which yielded 12,460 pounds tilapia per acre per year. In this latter experiment the fish were carefully placed in inch-groups and weighed, thus accurately measuring the yield. This pond was manured with 1,582 pounds per acre, flooded to a depth of 8 inches for one week, and subsequently filled. Pigs raised in pens over the pond added unknown quantities of manure throughout the experiment. The fish were fed daily with peanut cake, rice bran, and broken rice at the rate of 22,100 pounds per acre per year in the first experiment and 24,900 pounds in the latter. *S* conversions were 1.4 and 2.0 respectively, and the A_T values for the two populations 87.6 and 30.3. The high A_T value of 87.6 without the presence of a predator was apparently due to the removal of 107,488 young tilapia by seining 3 and 4 months after the start of the experiment. The annual rates of feeding used by Pongsuwana were approximately three times, and the annual production per acre 2.1 times that in the Alabama pond when both were recalculated to a standard 365-day experiment. It is therefore evident that the Java tilapia is capable of producing extremely high yields where large amounts of feeds are available. In Alabama ponds with only enough water added to replace that lost by evaporation and seepage, the highest rate of feeding used in any experiment was 100 pounds of Auburn No. 2 pellets per acre per day, which is over three times that considered

safe for most American pondfishes. No oxygen deficiencies or heavy phytoplankton scums developed, apparently because the tilapia utilized the feed, decaying organic matter, and plankton.

Production of Nile tilapia was similar in quantity to that of the Java tilapia (Table 1). Maximum total net production of the former species was 4,003.7 pounds per acre from 4,461 pounds of feed in Pond S-1258, compared to 4,198.4 pounds for the latter. The two species also appeared equally efficient in the utilization of feed as indicated by the *S* conversion values. The Nile tilapia appeared less prolific and consequently produced a higher percentage of harvestable fish in the absence of predation, as shown by the higher average A_T values in Table 1.

PRODUCTION IN ALABAMA PONDS OF TILAPIAS AND THREE AMERICAN PONDFISHES

The tilapias have been shown to produce a very high yield under conditions of heavy feeding. It must be remembered, however, that in areas of the world now lacking adequate high-quality proteins, feeds for fish are also in short supply. Consequently, the species giving highest production per acre may not be as desirable as one that is extremely efficient in conversion of feeds to fish flesh. Records of maximum productions per acre, most efficient *S* conversion values, and rates of growth of the speckled bullhead *(Ictalurus nebulosus marmoratus)*, the channel catfish *(I. punctatus)*, the common carp *(Cyprinus carpio)*, and the two tilapias in experiments in Alabama are given in Table 2.

Where only fertilization was used, the Java tilapia gave higher production and higher gains per acre per day than the speckled bullhead or the common carp. It would thus appear to have an advantage over these species in ponds where supplemental feeding is not possible. Comparative production figures on the Nile tilapia and the channel catfish without feeding were not available.

Where supplemental feeding was used, the tilapias were still outstanding in total production and in average gain per acre per day. Total production of the two tilapias, however, included large numbers of small fishes, while production of the other three species included only fish of harvestable size. Maximum production per acre of harvestable-sized Java tilapia was 2,453.1 pounds (Table 1), of the Nile tilapia 2,233.6 pounds (Table 3), and of the channel catfish 2,363 pounds. When compared on this basis, approximately equal

TABLE 1.—*Fish production per acre in fertilized ponds with and without feeding, when stocked with brood tilapia*

Pond number	Number stocked		Feed (pounds)	Fish produced		A_T	*S* conversion	Gain (pounds per day)	Days	Total fish (number)
	Tilapia brood	Bass fry		Total pounds[1]	Harvestable pounds					
Tilapia mossambica										
F-157	16	0	5,100	1,994.1	1,693.6	85.0	2.55	12.7	157	15,004
F-158	50	0	3,896	2,592.7	189.2	7.2	1.50	13.2	196	204,046
F-558	50	0	1,570	3,566.7	275.2	9.5	0.44	20.0	178	201,721
F-156	80	0	3,580	3,219.8	986.0	30.6	1.10	19.0	169	110,724
S-1158	100	0	4,030	4,198.4	900.0	21.6	0.96	21.5	196	132,179
F-1358	400	0	1,322	1,765.0	261.9	14.6	0.75	11.4	154	115,238
F-1458	400	0	1,392	1,792.1	318.4	17.5	0.76	10.1	177	207,395
F-356	80	0	0	1,477.1	139.2	9.4	—	8.8	168	137,332
S-1157	77	193	3,006	4,383.9	2,453.1	47.5	0.69	23.0	191	46,377
S-1958	410	100	1,405	1,078.7	634.0	58.4	1.30	5.5	197	34,206
F-1558	200	400	1,392	1,832.5	446.0	24.0	0.75	10.2	180	50,584
F-1658	168	800	1,292	1,824.2	450.3	24.5	0.70	13.0	140	44,398
S-1957	83	83	0	658.9	440.7	75.6	—	3.0	193	14,451
S-858	200	100	0	347.4	183.0	52.3	—	1.8	187	25,158
Tilapia nilotica										
F-1757	16	0	5,100	853.0	649.2	75.5	5.90	5.4	157	9,792
S-1258	100	0	4,461	4,003.7	1,621.0	40.1	1.11	19.2	208	69,647
F-658	164	0	1,522	2,205.3	1,069.6	48.0	0.68	12.3	179	115,080
S-958	100	100	2,520	1,880.0	1,316.6	71.0	1.35	9.6	196	42,098

[1]Total weight fish recovered on draining minus weight of fish stocked.

TABLE 2.—*Comparison of maximum productions, most efficient conversions, and rates of gain of tilapias and selected American species in experimental ponds in Alabama*

Species	Fish production per acre per season (March-October)				S conversion	
	Fertilization only		Fertilization and feeding			
	Total pounds	Gain (pounds per day)	Total pounds	Gain (pounds per day)	Total fish	Harvestable fish
Speckled bullhead	150-250	0.7-1.5	900-1,200	4-5	—	2.0-2.5
Channel catfish	—	—	2,003-2,363	7-11	—	1.2-3.0
Common carp	270-450	1.5	1,000-1,300	5-6	—	2.2-2.6
Java tilapia	1,480	8.8	1,795-4,389	10-26	0.4-1.1	1.2-5.0
Nile tilapia	—	—	2,380-4,003	9.6-21	0.7-1.4	1.4-2.7

maximum productions were obtained with the channel catfish and the two tilapias. The two tilapias gave this production in 191 days and 113 days, respectively, and the channel cat in 252 days. The second highest production of channel catfish per acre was 2,003 pounds, obtained in 188 days. These three species also were about equally efficient in food conversion and were superior to both the common carp and the speckled bullhead. These tilapias appear to be among the most desirable of the world's pondfishes for food production.

PRODUCTION IN PONDS STOCKED WITH BROOD TILAPIAS AND LARGEMOUTH BASS

The principal world-wide objection to tilapias as pondfishes is that a large part of the total production is composed of small fish in the 2- to 5-inch groups. Mono-sex culture has been tried in various areas to prevent reproduction and to increase the average size of fish (Chimits, 1957). Predation had not been previously tested for this purpose. In the present studies largemouth bass were added to ponds stocked with brood tilapias to eliminate most of the small fishes (Table 1). They were relatively effective, reducing the average numbers of tilapia per acre approximately 50 to 75 percent and increasing the A_T values. At the same time, predation reduced total production and often resulted in fewer pounds of harvestable fish per acre because it was not possible to feed heavily without killing bass; also, heavy feeding could not be used efficiently early in the season, because few fish had escaped predation at that time.

The earliest broods of tilapias were usually small, and consequently these individuals rapidly grew too large for small fingerling bass to eat. When largemouth bass were stocked in excess of 100 per acre, few were able to grow large enough to feed upon 3- and 4-inch tilapias. The maximum production of bass in such combinations was 73 pounds per acre. Low production was due to the very short period during which the young tilapia were available to bass and to the small size (1 to 2 inches) of the bass stocked.

When 100 bass of the 1-inch group per acre were stocked with brood tilapia April 15 to 20, they were able to attain an average size of 0.3 to 0.5 pound by the following August 1, when the ponds were open to fishing. This growth was much faster than that obtained in bluegill-bass populations.

When brood tilapias were stocked in established bluegill-bass populations in May, they were found to reproduce in May or June, but the young subsequently disappeared, apparently victims of bass predation. Hofstede and Botke (1950) also have reported that the Java tilapia became abundant in Indonesian waters only where predation was absent.

The most effective use of bass predation was in Pond S-1157, where bass were not added until August. At this time many young-of-the-year tilapia were too large to be eaten, but the addition of bass reduced the survival of tilapias which hatched subsequently. The rate of feeding was then doubled, causing many of the larger fingerling tilapias to grow to harvestable size. This procedure resulted in a production of 2,453 pounds harvestable fish per acre (Table 1).

Where feeding is practiced and the fish being cultured can survive at high rates of feeding, it is apparently possible to substitute changes in rates of feeding for predation to produce harvestable crops of fish. In the absence of supplemental feeding, a predator must increase the available food for surviv-

ing individuals by continuously reducing the numbers of fish. The same end could theoretically be achieved by periodically doubling the amount of feed available, with the number of individuals remaining constant. In natural populations, A_T values in excess of 33 are characteristic of populations balanced by adequate predation. Periodically increased rates of feeding accomplished the same purpose in Ponds F-157, F-1757, S-1258, and F-658, with resulting A_T values of 85, 75.5, 40.4, and 48.0, respectively (Table 1).

PRODUCTION OF TILAPIAS WITH FINGERLING STOCKING

Another possibility for the production of a high percentage of harvestable tilapias without predation is to stock young-of-the-year fingerlings. If these fish could reach a desirable harvestable size before they spawned heavily, production of undesirable small fish would be reduced or eliminated. A similar procedure was used for commercial production of the speckled bullhead (Swingle, 1954). The Java tilapia, however, was found to spawn at an age of 3 months and below the minimum harvestable size of 6 inches.

A second possibility remained with fingerling stock — the use of the repressive factor to control reproduction (Swingle, 1957a). This procedure involves stocking at such a rate that fish grow readily, but by the time they are sexually mature, they have excreted or secreted into the water sufficient amounts of a repressive factor to reduce materially or prevent reproduction. This practice is used in carp culture and was used to develop a system of commercial culture of the speckled bullhead (Swingle, 1957b). Results of experiments with various rates of stocking fingerling tilapias are given in Table 3.

The Java tilapia, in fertilized ponds without feeding, produced 282 and 360 pounds per acre at stocking rates of 2,000 and 4,000 fingerlings within a period of 126 and 119 days, respectively. This production is equivalent to 817 and 1,104 pounds per acre per year which can be compared with Asiatic production figures. With feeding, there was a continued sharp increase in total production from 771.1 pounds per acre in 123 days with a stocking rate of 4,000 fingerlings per acre, to 2,945.7 pounds per acre in 111 days with a stocking rate of 20,000 fingerlings. This yield is equivalent on the basis of 365 growing days per year to annual productions of 2,291 and 9,685 pounds per acre.

The percentage of harvestable-sized Java tilapias declined, however, from A_T 98.7 with the lowest stocking rate to A_T 67.7 at the rate of 20,000 fish per acre. The maximum production of harvestable tilapias was 2,063 pounds per acre in 111 days, equivalent to 6,783 pounds per acre per year. There were some indications of repressed reproduction with increasing rates of stocking, but at none of the rates tested was reproduction prevented.

The possible presence of a repressive factor affecting reproduction of the Nile tilapia was indicated in the two experiments conducted. No reproduction occurred at the stocking rate of 16,000 and very limited reproduction at

TABLE 3.—*Production per acre of tilapias in fertilized ponds with and without feeding, when stocked with fingerlings*

Number stocked	Feed (pounds)	Fish production		A_T	*S* conversion	Gain (pounds per day)	Total days	Reproduction (number)
		Total pounds[1]	Harvestable pounds					
Tilapia mossambica								
4,000	2,020	771.1	771.1	98.7	2.57	6.3	123	2,584
8,000	2,440	1,430.1	1,430.1	99.7	1.67	11.7	122	1,264
10,000	1,948	1,785.6	1,684.8	88.9	1.10	19.7	91	28,183
20,000	3,240	2,945.7	2,063.0	67.7	1.10	26.6	111	8,718
2,000	0	282.3	276.0	97.5	—	2.2	126	4,288
4,000	0	360.0	181.6	50.4	—	3.0	119	60
Tilapia nilotica								
8,000	2,520	1,381.0	1,373.4	98.5	1.80	12.1	114	44
16,000	3,300	2,380.0	2,233.6	91.9	1.35	21.0	113	0

[1]Weight of tilapia recovered on draining minus weight stocked.

8,000. The production obtained was 1,381 pounds per acre in 114 days with the lower rate of stocking and 2,380 pounds in 113 days at the higher rate. This yield is equivalent to 4,420 and 7,687 pounds per acre per year on the basis of a 365-day growing period. The Nile tilapia produced 70 pounds more harvestable fish per acre at a stocking rate of 16,000 than did the Java tilapia at 20,000 per acre.

It would thus appear that rates of growth of the tilapias, during the period from May to October in Alabama, approached that obtained in tropical countries. Except for purposes of comparison, however, the calculations involved in conversion of results of short-time tests to a full-year production used in tropical areas is not valid in temperate climates where practically no growth can be obtained during 5 to 6 months of the year.

USE OF TILAPIAS AS SPORT FISHES

Preliminary tests using the two tilapias as game fishes were conducted. Ponds were stocked April 15 to 20 with 80 brood tilapias per acre. Young fish hatched by May 1 and were fed 6 days weekly until October. They were 6 to 8 inches long at the end of 3 months and the ponds were open to public fishing in August, September, and October. The catch per acre in ponds stocked with the Java tilapia was 593.6 pounds in 1957 and 590.6 in 1958. This catch is over twice the average from bluegill-bass ponds during the second year after stocking. Most of the tilapias were caught by fishermen using worms for bait. The Nile tilapia were stocked and grown in a similar manner but were harder to catch. Fishermen removed only 128 pounds, although the pond contained 1,621 pounds of fish of harvestable size per acre. It is possible that with more experience with this species, fishermen will learn to increase their catch greatly.

Tilapias appeared to be capable of furnishing fishing within a short period of time. In southeastern United States this fishing can only be made available in late summer and fall, because the tilapias cannot live over winter in ponds. The greater part of the fishing load, however, comes in the spring months. The tilapias available for fishing are principally in the 5-, 6-, 7-, and 8-inch groups because of the short growing period. Additional experiments using tilapias as sport fishes in various combinations are now in progress. It appears probable that they may prove useful as sport fishes under a variety of conditions, but further studies will be necessary to devise methods of management and to measure fishermen's acceptance of these species.

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The Use of Lead Versenate to Place a Time Mark on Fish Scales

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ABSTRACT

Injection of 5 to 7 percent lead disodium versenate at a level of 50 milligrams per kilogram body weight consistently produced satisfactory deposits of lead in the scales of whitefish and lake trout and appears to offer advantages over the original lead-acetate method of Hiyama and Ichikawa for producing time marks. The injection appeared to have no effect on mortality or growth, but it was not established whether the handling produced a check in the scale growth. As with injection with lead acetate, lead is deposited in the scale at the margin within a few days of injection (probably 1 or 2). Growth of the scale and the body were shown to be closely proportional in the whitefish over a period of a year. The results of a few preliminary experiments to compare the efficiencies of lead acetate and lead versenate as producers of lead lines on fish scales are also reported. The methods of preparation of the lead versenate and of developing the lead lines are given.

INTRODUCTION

The successful application to fish of the lead-line method of marking bone by Hiyama and Ichikawa, who pointed out its value for placing a time mark at the margin of the scale at the time of injection (1952, 1953), led us to inject the lake whitefish (*Coregonus clupeaformis*) with lead acetate following their method. These fish were tagged and released in South Bay, an inlet in Manitoulin Island, Lake Huron. The scales of the three fish recovered from the group thus injected and released showed lead lines. However, we found it difficult to inject the large amount of liquid necessary to carry the dosage of lead required.

At the suggestion of Dr. H. Boroughs, then working at the Hawaii Marine Laboratory, lead disodium versenate was substituted for the lead acetate. Lead versenate is stable in a neutral solution and can be injected in a more concentrated form than can lead acetate. It appears to be considerably less toxic and equally effective in providing the lead to be laid down in the bone.

PREPARATION OF LEAD VERSENATE

The lead versenate was prepared in two ways. Originally it was prepared from lead acetate as follows: Add 20 percent sodium hydroxide solution slowly to a 10 percent solution of lead acetate, $Pb(C_2H_3O_2)_2 \cdot 3\ H_2O$, in distilled water until no more of the dense white precipitate is formed. Approximately 25 milliliters of hydroxide will be required per 100 milliliters of 10 percent lead acetate. The production of the precipitate is complete at a pH of approximately 8. A slight excess is not harmful but do not allow the liquid to become strongly alkaline. Add an approximate 20 percent solution of disodium dihydrogen versenate until the precipitate is completely redissolved. Approximately 50 milliliters will be required per 100 milliliters of acetate solution. A slight excess of sodium versenate is not harmful. Adjust the pH of the solution to neutrality. Add distilled water to make up the weight appropriate to a 5 percent solution of lead acetate—*e.g.*, to 200 milliliters if 100 milliliters of 10 percent lead acetate was used for the preparation.

The procedure above was adopted to provide solutions of similar lead content for the comparisons with lead acetate recorded in Table 1. The same strength solution was also used in the field injections in 1957 and in the early part of 1958. The concentration of this solution expressed as lead versenate is approximately 7 percent.

The second method of preparation began with lead oxide, PbO, and proceeds as fol-

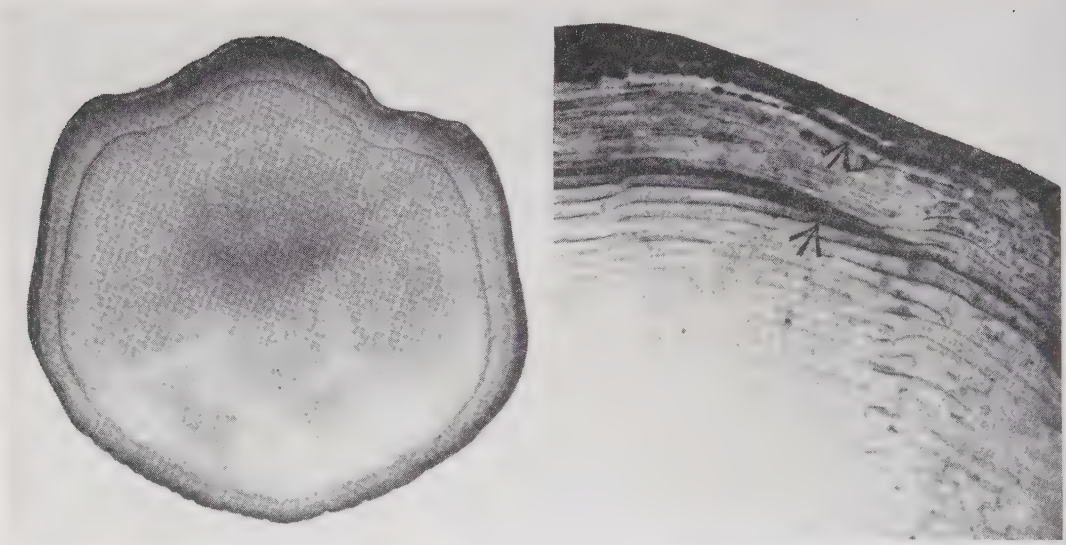

FIGURE 1.—Typical lead lines. Left: Scale from a South Bay whitefish injected in 2 successive years and finally recovered a few weeks after the second injection. Note that the circuli are continuous through the mark suggesting no check in growth due to the injection. The dark margin of the scale is an artifact in the photograph; in direct observation the margin was clear. The freshly developed marks are a clear, pinky blue. Right: Enlargement of portion of scale. Arrows indicate lines of deposition.

lows: 5.40 grams of versene acid are slurried in 150 milliliters of distilled water and 4.10 grams of lead oxide added. This slurry is heated to near boiling and, with continual stirring, 18-19 milliliters of 7.5 percent solution of sodium hydroxide is added slowly, the solution being kept near boiling during this time. Next the solution is allowed to cool to approximately 75° C. and the pH adjusted to 7.0, using 1-2 milliliters further of the sodium hydroxide solution for this purpose. Finally, sufficient distilled water is added to make the total volume of the solution 200 milliliters to make a 5 percent solution.

We are indebted to R. D. Spitz, Technical Service and Development Department, Dow Chemical Company, for the second method. The Dow Company also kindly supplied a quantity of versene acid for our use. This latter solution has been used since late in the season of 1958. No change was made in the dosage table to compensate for the weaker solution.

DEVELOPMENT OF THE LEAD LINE

To develop the lead line, the scales were treated essentially as recommended by Ichikawa and Hiyama (1954) except that the excess sulphide was removed by soaking the scales in methanol instead of water. The scales were placed in small containers (approximately 10 milliliters) with suitable tight stoppers. The container was filled with 5 percent hydrochloric acid saturated with hydrogen sulphide while chilled in ice and water. The scales were placed in the acid solution and allowed to soak for 4-8 hours at room temperature, being agitated at intervals. During this process the container was kept stoppered, and air spaces were avoided when closing it. Large scales require a longer time and a larger quantity of reagent. The container was then drained and refilled with methanol. Again it was agitated at intervals. It is very important to allow a thorough soaking in the methanol, at least 12 hours for most scales. The methanol was then removed and replaced with about the same volume of 0.05 percent gold chloride. The scales were examined from time to time for the appearance of the pinky-blue lead line. The line generally develops within the first 2 hours. If the scales are left in the gold chloride too long, they become dark. When the lead lines were developed, the gold chloride solution was removed and replaced with 0.5 percent sodium thiosulphate. After a brief treatment the scales were rinsed in water or transferred to an alcohol series for dehydration preparatory to mounting in euparol.

COMPARISONS OF LEAD ACETATE AND LEAD VERSENATE

A brief series of experiments was carried out to compare the efficacy of the two forms of lead (Table 1). The experiments were conducted in 1955 and 1956. Except for the maskinonge, which were treated at the Provincial Hatchery at Deer Lake, the fish were kept in running lake water at the South Bay laboratory in 1955 and during 1956 in well water at the Laboratory for Experimental Limnology, Ontario Department of Lands and Forests, Maple, Ontario.

In general, the versenate is somewhat more effective and somewhat less toxic than the acetate. It was further concluded from these experiments that a dosage of 50 milligrams per kilogram body weight was an effective dose of lead versenate and that the dosage could safely be doubled. Dosages used subsequently in the field trials were based on this conclusion.

FIELD TRIALS

Following the experiments summarized in Table 1, field trials were carried out in South Bay, Lake Huron, and in Georgian Bay. Two species of fish, the lake trout (*Salvelinus namaycush*) and the lake whitefish, were injected and released for later recapture. The fish were taken in pound nets, anesthetized with tricaine methanesulfonate (M.S. 222), measured for fork length, tagged, and either injected with lead versenate or released without injection as controls. After the initial work in 1957, when the schedule of release of experimental fish and controls was irregular, fish tagged in South Bay with even numbers were injected, those with odd numbers released without injection. All the fish tagged in Georgian Bay were injected.

The injection solution contained 5 percent lead versenate and was injected from a glass hypodermic syringe through a short fine needle (25 gauge, 1 inch long) into the dorsal body muscle. To prevent loss of the solution the needle was inserted at a slight angle as deeply as possible in the muscle and the fluid injected slowly. The dosage for each fish was determined by referring its length, measured to the nearest half inch, to a dosage chart,

TABLE 1.—*Relative efficiencies of lead acetate and lead disodium versenate as agents for placing a time mark on fish scales*

[Dosage is expressed in milligrams of lead acetate per kilogram of body weight.]

Treatment	Species	Dosage	Solution (percentage)	Effect	Toxicity	First appearance of mark (days)
Lead acetate	*Coregonus clupeaformis*	10	0.1	+	−?	5
	Micropterus dolomieui		0.1	+	−	14
	Catostomus commersoni		0.1	+−	−	..
	Ambloplites rupestris		0.1	+−	−	.
	Coregonus clupeaformis		5.0	−	−	
	Cyprinus carpio		5.0	+−	−	..
	Perca flavescens		5.0	−	−	.
	Salvelinus fontinalis	50	0.5	+−	+−	..
	Micropterus dolomieui		2.3	+	−	?
	Coregonus clupeaformis		5.0	−	+	..
	Cyprinus carpio		5.0	−	−	..
	Perca flavescens		5.0	+	−	30
	Salvelinus fontinalis	100	1.0	+	+−	?
	Salvelinus fontinalis	500	1.0	?	+¬	
Lead disodium versenate	*Cyprinus carpio*	10	5.0	+	−	1
	Perca flavescens		5.0	+−	−	.
	Esox masquinongy	25	0.5	+	−	?
	Esox masquinongy	50	0.5	+	−	3
	Salvelinus namaycush		5.0	+	−	1
	Coregonus clupeaformis		5.0	+	−	5
	Cyprinus carpio		5.0	+	−	1
	Catostomus commersoni		5.0	+	−	1
	Perca flavescens		5.0	+	−	1
	Cyprinidae	100	5.0	+	−	1
	Cyprinidae	500	5.0	+	−	1
	Cyprinidae	1,000	5.0	+	−	1

or by relying on a practiced fisherman to estimate the weight of the fish. The dosage chart provided a dose of 50 milligrams per kilogram based on the mean weight-length relation for the species. When the weight was estimated, the dose administered was 0.5 milliliter of the 5 percent solution per pound estimated. Various members of the staff of the South Bay Fisheries Laboratory have carried out the program of injection and tagging as a routine part of their work. Except to provide general instructions and the dosage chart, nothing was done to standardize the procedure.

The releases and recaptures of these fish through August 1959 are summarized in Table 2. No difference has been observed between the survival of the injected fish and the controls, and there does not appear to have been any difference in the rate of growth between the two groups (Table 3). The injections were more successful in the whitefish than in the lake trout, there being 86 percent positive findings in the recoveries from the former species as opposed to 69 percent from the lake trout recoveries (Table 4).

TABLE 2.—*Returns through August 1959 of injected and non-injected fish released in South Bay*

Species	Year of release	Injected		Non-injected	
		Releases	Recaptures	Releases	Recaptures
Lake trout	1957	358	80	105	27
	1958	348	75	334	59
	1959	80	5	88	2
Whitefish	1958	145	22	153	21
	1959	398	49	393	48

The lead was laid down rapidly in the fish released, as was found by Hiyama and Ichikawa and in the experiments summarized in Table 1. While the lines were clear in both species, it is difficult to flatten the lake trout scales and these have not been examined critically. The whitefish scales are easily examined and early recaptures show that the lead is deposited just inside the margin of the scale (Figure 1). It was not possible to decide whether the action of tagging and injecting the fish caused a check in the scale growth because the fish were released at the season when there is still little scale growth of the current year, and a false annulus, if formed, would thus have merged with the annulus of the year.

TABLE 3.—*Growth of injected and non-injected fish in South Bay*

[Number of individuals in sample given in parentheses after initial length.]

Interval	Species	Treatment	Fork length on release (inches)	Increment (inches)
1957-58	Lake trout	Not injected	15.3 (10)	4.4
		Injected	15.6 (19)	3.8
1958-59	Lake trout	Not injected	16.2 (7)	3.6
		Injected	16.3 (23)	3.7
1958-59	Whitefish	Not injected	14.7 (12)	1.9
		Injected	14.5 (12)	2.0

SCALE-BODY GROWTH RELATION

Since the fish were measured at release and on recapture, the marked scales can be used to provide a direct test of the validity of the method of back calculation of growth from scale measurements. For this purpose the scales of the Georgian Bay whitefish that had been at large for a year were used. To check for change in size during the decalcification and development process, a cellulose-acetate impression was made of each scale before it was treated. The impression was projected and its outline drawn. The mounted preparation was then projected at the same magnification and compared with the outline of the impression. In 30 cases so measured, the mounted preparation averaged 1.3 percent larger than the impression. As a further comparison the circuli stained by the lead on the preparation were identified on the impression and then the ratio of the antero-postero diameter of the scale at release as indicated by the lead line, to that on recapture, was calculated from the impression

TABLE 4.—*Results of field injections with lead versenate—expressed as numbers of fish examined at various intervals after injection*

[Lake trout data to end of 1958 only; whitefish data for South Bay and Georgian Bay combined.]

Species	Reaction	Days after injection						Total
		1-2	3-4	5-6	7-8	9-10	over 10	
Lake trout	Negative	5	0	4	2	0	23	34
	Doubtful	0	0	0	0	0	10	10
	Positive	3	2	2	3	1	86	97
Total								141
Whitefish	Negative	6	5	1	1	1	5	19
	Doubtful	3	0	0	0	0	1	4
	Positive	9	24	9	6	4	89	141
Total								164

and from the preparation. The two calculations gave essential agreement. Twenty-six mounts gave a scale-growth ratio 0.8 percent greater than the corresponding body-growth ratio, with an average deviation of 3.7 percent. The scale-growth ratio for 25 impressions was 0.4 percent less than the body-growth ratio, with an average deviation of the individual comparisons of 2.2 percent. The mean increase in body length over the year the fish were out was 13.5 percent.

ACKNOWLEDGMENTS

The authors are indebted to Mr. J. C. Budd, in charge of Lake Huron investigations, and the members of the staff of the South Bay Fisheries Research Station, for carrying out the field work. W. J. Perks and the Harrower Brothers, who operate fisheries in Georgian Bay and Lake Huron, were helpful in permitting fish to be injected and released from their nets. These and other fishermen also cooperated in providing scales and measurements from tagged fish subsequently recovered.

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Disappearance of Young Atlantic Croakers from the York River, Virginia[1]

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ABSTRACT

Virginia catches of the Atlantic croaker, which declined from 55 million pounds in 1945 to 3½ million pounds in 1952, apparently began to recover in 1955, reaching a total of 9½ million pounds. Recent information suggests that catches are again declining. Length measurements on croakers from commercial pound-net catches made since 1950 show a general increase in length and therefore average age of fish since 1954. Monthly young fish surveys made in croaker nursery areas of lower Chesapeake Bay and York and Pamunkey rivers indicate differences in the relative abundance of young croakers from one year to the next. The winter season of 1957-1958 was especially unique in that considerable numbers of young were present in fall but disappeared in mid-winter. The disappearance of young croakers occurred during a period when water temperatures dropped below those in preceding years. It is suggested that extreme low temperatures may have affected the abundance of young croakers.

INTRODUCTION

Atlantic croaker *(Micropogon undulatus)* catches in Virginia declined from a high of more than 55 million pounds in 1945 to about 3½ million pounds in 1952 (Figure 1). Since 1952, catches have increased to 9½ million pounds, but recent information suggests that catches are again declining. A study of the croaker was begun in 1950 by Dexter Haven to whom we are indebted for length-frequency and trawl-catch data through 1954.

Length measurements have been taken on catches from commercial pound nets located at the mouth of the York River almost every week of the fishing season from 1950 through 1958. The size composition of the yearly catch, not weighted by annual poundage, is summarized in Figure 2. The average size of croakers in these pound-net samples has increased since 1954 indicating that young croakers are now relatively less abundant than they were during the period from 1950 to 1954.

Croakers are believed to spawn off the mouth of Chesapeake Bay. Spawning begins in late summer and fall and may continue through winter. Recently hatched young migrate into the Bay and tributaries where they move upstream and concentrate in waters of low salinity. Haven (1957), sampling with a 12-foot, ½-inch stretched-mesh shrimp trawl, located young croakers in brackish waters of the James, York, and Rappahannock rivers. The young remain in the Bay and rivers during winter, spring, and summer and return to the ocean in fall when they are about 1 year old. Adult croakers move into the Bay in spring and migrate back to sea to spawn in late summer and fall. Since spawning may continue all winter, January 1 is defined as the birth date for each year class, but the 1958 year class may begin to appear in late summer and fall of 1957.

TRAWL SAMPLING

To investigate distribution and abundance of fishes in Virginia tidal waters, monthly trawl surveys were begun in April 1956 and have been continued with few interruptions to the present time. Using a 30-foot semi-balloon shrimp trawl having 1-inch (stretched measure) mesh in the wings and body and ¾-inch mesh in the cod end, 16 stations separated by intervals of approximately 5 nautical miles were sampled. Stations were located from the mouth of Chesapeake Bay to fresh water in the Pamunkey River (Figure 3). Since earlier hauls made by Haven (1957) show that single tows give a reasonable estimate of the availability of young croakers at a given station at a given time, a single 15-minute tow was

[1]Contributions from the Virginia Fisheries Laboratory No. 91.

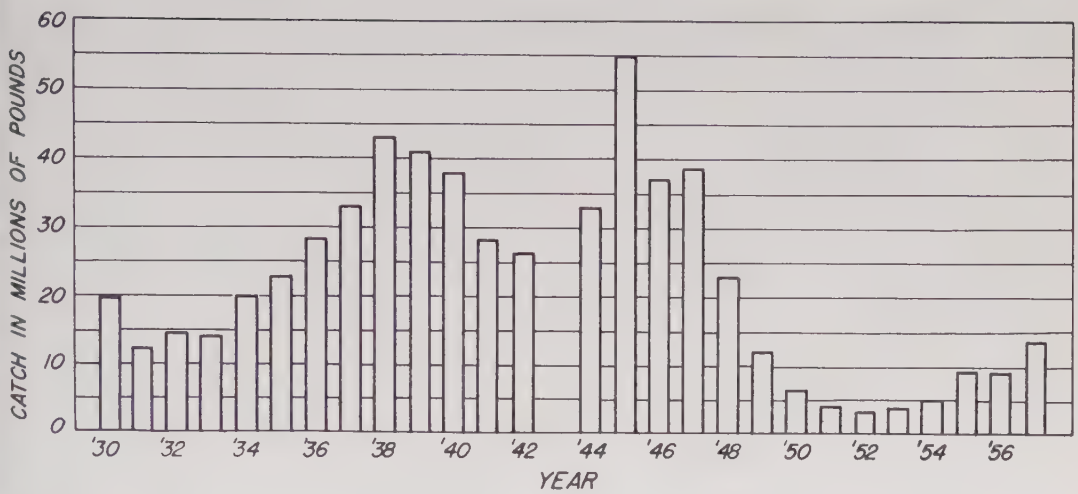

FIGURE 1.—Catches of croakers in Virginia from 1930 to 1957. Source: U. S. Bureau of Fisheries 1931-1941 and U. S. Fish and Wildlife Service 1942-1958.

made at each station in the same direction as the tidal current.

To determine if tidal currents affected catches of young croakers, hauls made during flood, ebb, high slack, and low slack tides were compared by analysis of variance. There was no significant difference ($F=0.39$) in means of catches made at different tidal stages.

CROAKER CATCHES

Numbers of young croakers captured by trawl each month are shown in Table 1. Collections made during the period 1951 to 1954 were obtained by Haven (1957). Although his net was not the same size as the one used in the present survey and trawling effort was not uniform, the results indicate that many young croakers were present during the fall, winter, and spring. Catches of the 1956 year class suggest that young croakers of this group were scarce. The 1957 year class was more abundant and substantial numbers of young were taken in the fall, winter, and spring. The 1958 year class is of special interest, because young croakers were caught in considerable quantities in August, 2 months earlier than they had been found in previous years. The early appearance of numbers of young suggested that a strong year class had appeared. In January, however, catches decreased and in February almost no young croakers were captured. Young were rarely taken in subsequent spring and summer surveys.

The scarcity of young croakers was not confined to the York River system and lower

TABLE 1.—*Numbers of croakers trawled each month from March 1952 through July 1958*[1]

Month	Year class					
	1952	1953	1954	1956	1957	1958
August	—	—	(0)	—	0	279
September	—	—	(40)	—	0	338
October	—	(61)	(581)	—	57	152
November	—	(217)	(1,264)	—	129	102
December	—	(122)	(656)	—	529	358
January	—	(29)	—	—	212	25
February	—	(209)	(527)	—	59	6
March	(103)	(501)	(118)	—	162	0
April	(73)	(320)	(417)	5	—	0
May	(88)	(494)	(49)	40	2,068	1
June	(304)	(288)	—	—	—	6
July	(210)	(135)	—	148	—	0

[1]Since effort was not always uniform during the period 1952-1954 indices of abundance, indicated by catches in parentheses, are approximate.

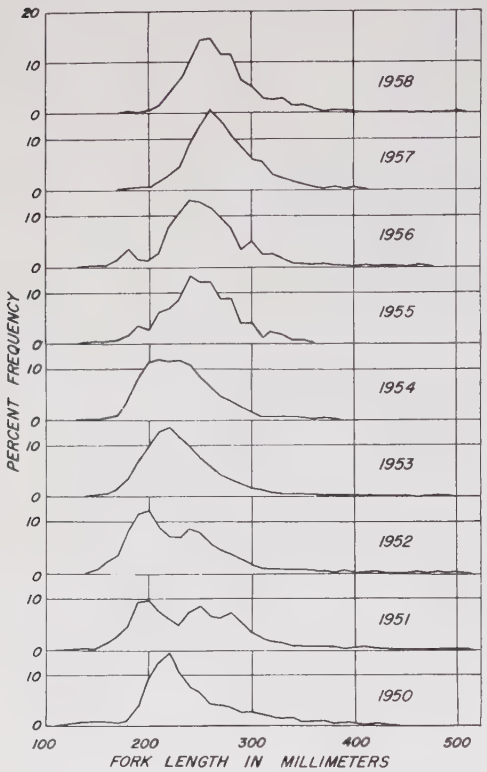

FIGURE 2.—Length frequencies of croakers sampled from commercial pound nets located at the mouth of the York River during the period 1950 to 1958.

Chesapeake Bay. Surveys were made in cooperation with the Chesapeake Biological Laboratory of Maryland throughout the entire Bay. Twenty-four stations located at 7-mile intervals from the mouth of the Bay to Havre de Grace were trawled in the same manner as the York River stations. A few young croakers were captured during a cruise made in January 1958; however, none were obtained on cruises made in April and July. During spring and summer in 1958 trawling was done in the James and Rappahannock rivers to obtain live croakers for tagging. No young croakers were obtained in these hauls. In addition, young croakers were noticeably absent from fall pound-net catches.

To relate catches by trawl to those made by commercial pound nets at the mouth of the York River, length compositions of croakers were compared by months for the 1956, 1957, and 1958 fishing seasons (Figure 4). Trawl catches included young croakers as well as older fish, while in pound-net catches older fish predominated. Since the mesh size for the trawl was smaller than that used in commercial pound nets (¾-inch as compared with 2-inch), the trawl would be expected to sample small fish more effectively while pound nets would be more effective for large fish.

In 1956 from May through August large croakers made up the bulk of catches by trawl and pound net, but after August few large fish were captured by trawl. While a few young croakers were trawled in July and August, in September young made up the bulk of catches.

In 1957, May trawl catches included both young and older croakers while pound nets caught only older fish. During the rest of the season trawl samples consisted almost entirely of young, and, with the exception of late summer and fall when some young were also taken, pound-net catches were mostly composed of older individuals. In 1958, trawl and pound-net catches consisted almost entirely of older, larger croakers. Young were almost completely absent from catches by both gears. For the 1958 year class, successful spawning was indicated by the presence of large numbers of young in trawl hauls made in the fall of 1957. Young croakers almost completely disappeared from samples obtained in mid-winter and few were taken the following spring or summer.

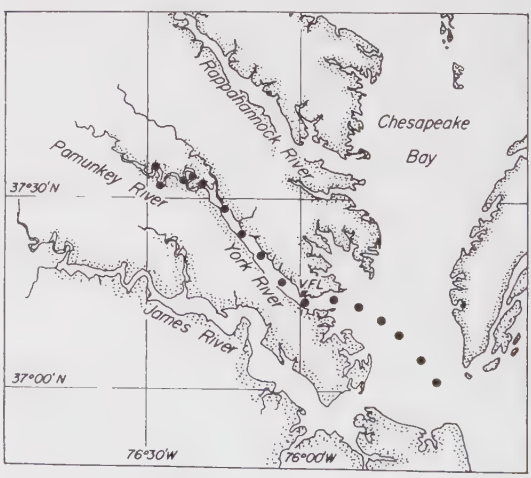

FIGURE 3.—Lower Chesapeake Bay, York and Pamunkey Rivers. Trawl sampling stations are indicated by black circles.

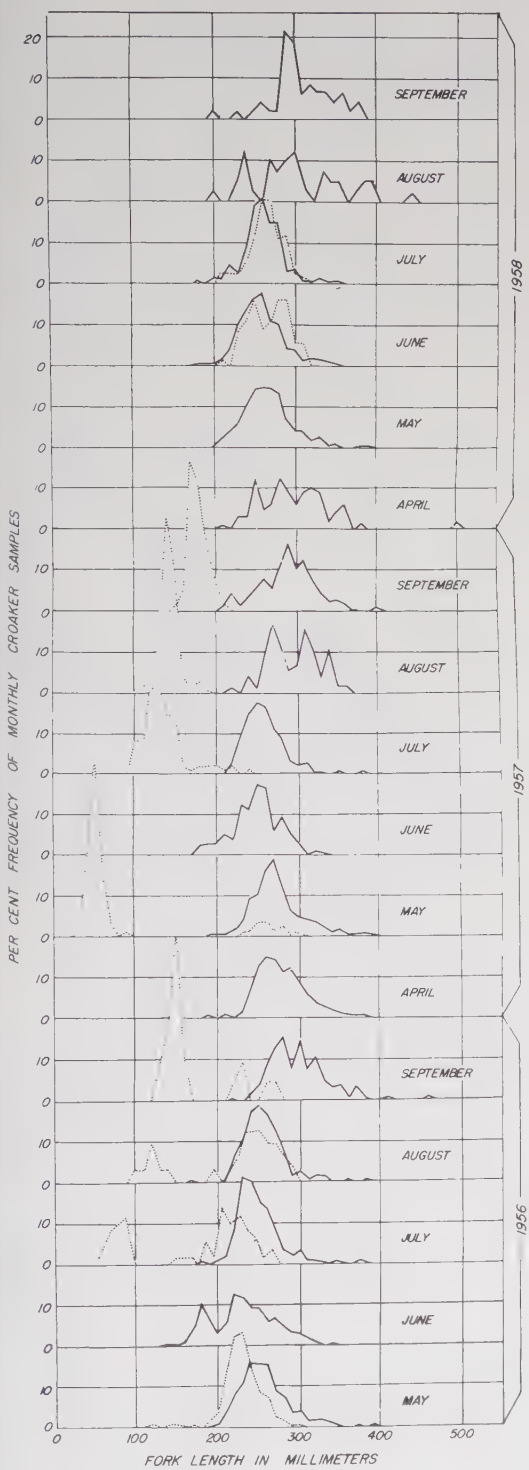

FIGURE 4.—Comparison of the lengths of croakers sampled each month during the fishing season from commercial pound nets and trawl hauls made from 1956 to 1958. Croaker lengths from pound nets are shown by solid lines and lengths from trawl hauls by dotted lines.

WATER TEMPERATURES

Since the sharp decline in catches occurred in January and February when water temperatures are usually lowest, temperatures recorded during the winter months have been examined (Table 2). Daily water temperature records observed from the laboratory pier are available since 1950. From 1950 to 1952 daily readings were made in connection with tidal observations for the U. S. Coast and Geodetic Survey Tide Gauge Station and from 1953 to 1958 temperatures were obtained from a thermograph[2] installed on the pier. Since minimum temperatures are of primary interest, only minimum temperatures observed each month were included. During the winter of 1957-1958 water temperatures were not only colder than any year since 1950 but for a continuous 8-day period remained colder than temperatures observed in other years.

To find how closely bottom water temperatures recorded at each station during the winter cruises corresponded with temperatures observed during the entire month, the mean maximum and minimum temperatures observed for each cruise are compared with those recorded on the pier thermograph. As indicated in Figure 5, cruise temperatures correspond fairly well with those observed at the laboratory for the entire month.

DISCUSSION

Low temperatures might have stimulated young croakers to migrate from their usual winter nursery areas in the upper York and Pamunkey rivers to warmer ocean water outside of Chesapeake Bay. If this were the case, concentrations of migrating young would be expected in trawl hauls made in the lower York River or near the mouth of Chesapeake Bay during December or January cruises. For these months, however, most young were captured in the upper York River. Because young croakers did not reappear in the Bay during the spring or summer months in 1958. it is believed that no substantial migration had occurred.

[2]McHugh, J. L. (1959) Maximum-minimum water temperatures, York River, Virginia 1952-1958. Va. Fish. Lab. Spec. Sci. Rept. No. 16. Mimeo.

TABLE 2.—*Minimum winter water temperatures in degrees Fahrenheit observed for York River at Gloucester Point from 1950 to 1958*

[Records from 1950 to 1952 are from daily temperature readings and those from 1953 to 1958 were obtained from a Foxboro temperature recorder.]

Year	Month				
	November	December	January	February	March
1950 - 1951	45.5	37.0	38.5	37.5	45.0
1951 - 1952	47.5	40.5	39.5	42.0	42.0
1952 - 1953	51.0	42.5	42.0	43.5	44.0
1953 - 1954	48.0	39.5	36.0	36.0	42.0
1954 - 1955	46.0	36.0	33.5	32.0	41.5
1955 - 1956	44.0	34.5	33.0	35.0	42.0
1956 - 1957	45.5	42.0	34.0	40.0	42.0
1957 - 1958	49.0	38.0	34.5	30.0	36.0

That croakers are less sensitive to cold water than many other fishes is suggested by their absence from lists of fishes killed by cold in Florida waters (Storey and Gudger, 1936; Storey, 1937; Miller, 1940). Croaker mortalities attributed to cold water, however, are not unknown. They have been reported at Beaufort, North Carolina (Hildebrand and Cable, 1930), and on the south Texas coast (Gunter and Hildebrand, 1951). In spite of the fact that small croakers are known to be less sensitive to cold than larger individuals (Hildebrand and Cable, 1930; Gunter, 1938) there are undoubtedly lower limits below which they cannot survive. It seems possible that in this case temperatures may have fallen below the limit of survival for young croakers and that substantial numbers of the 1958 year class in Virginia waters were destroyed. The value of continuous series of biological observations as pointed out by Gunter (1952) seems apparent. The need for controlled temperature experiments on young croakers is also indicated.

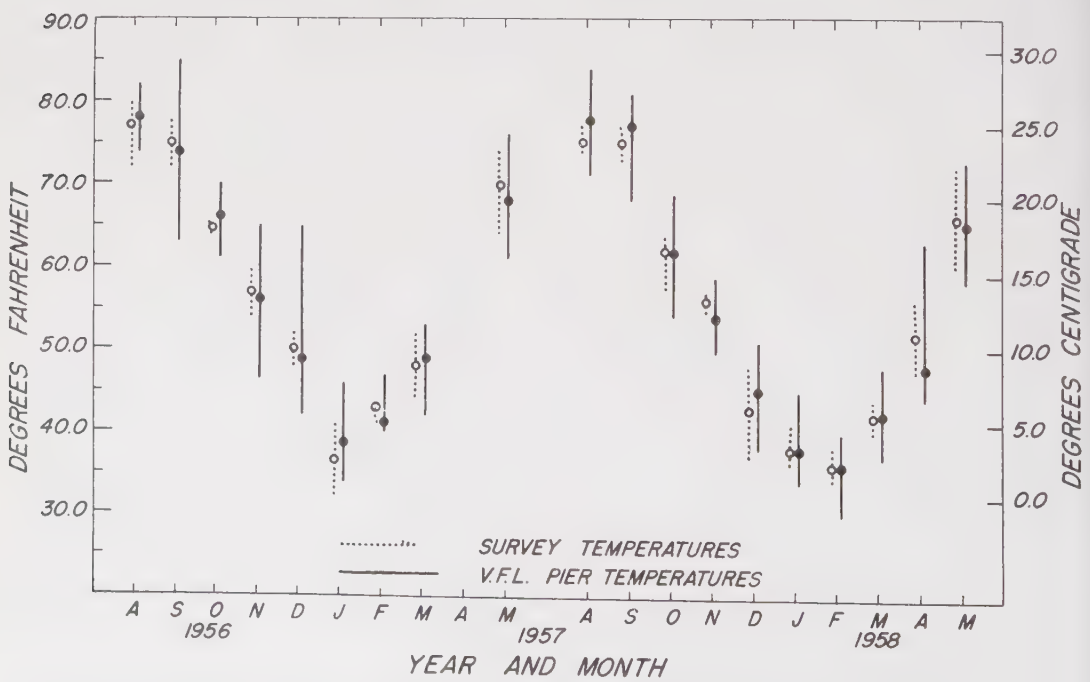

FIGURE 5.—The maximum, minimum, and mean bottom water temperatures obtained on monthly trawl survey cruises and those recorded at the Virginia Fisheries Laboratory pier during the entire month.

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A Virus-like Disease of Chinook Salmon

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ABSTRACT

Consideration is given to a recurring disease of early feeding chinook salmon fingerlings at the Coleman, California, Federal Fish Cultural Station. The infection becomes manifest in the early spring months at low water temperatures and abates as the water temperature rises. Bacteriological studies have failed to yield the presence of a disease agent, either by cultural or staining procedures. The disease has been successfully transmitted from infected fish to healthy fish by the injection of bacteria-free filtrates prepared from diseased fish tissues. The causative agent is therefore believed to be a virus-like entity.

INTRODUCTION

The Coleman Fish Cultural Station, situated on Battle Creek, California, about 6 miles above the junction of that stream with the Sacramento River, was put into operation in 1941. This station was deemed necessary in order to accommodate spring and fall run chinook salmon *(Oncorhynchus tshawytscha)* that would be prevented from reaching their natural upstream spawning areas on the Sacramento River following construction of Shasta Dam. A report on the early operations of the Coleman Hatchery is presented in some detail by Cope and Slater (1957).

Since the inception of this station, exceedingly high mortality rates have occurred on occasion among feeding chinook salmon fingerlings following their removal from inside hatchery troughs to outside rearing ponds. The infectious agent appears to be specific for chinook salmon, since coho salmon *(O. kisutch)*, rainbow and steelhead trout *(Salmo gairdneri)*, and kamloops trout *(Salmo gairdneri kamloops)* are reared in the same hatchery and have never contracted the infection.

The disease has never been recognized in wild populations, although it is suspected that it may be a contributing factor in the depletion of natural stocks in the Sacramento River. At the present time no information is available which would indicate that this disease occurs in other rearing stations.[2] The infection usually occurs at the Coleman hatchery in the spring of the year when the water temperature is about 45° F. and the first fish to hatch have begun feeding. Once the infection becomes apparent the mortality rate continues to rise and eventually may amount to 60 percent or more of the fish present. As the water temperature rises to 50° F. or above, the mortality rate is markedly less than at the lower temperatures, and the disease appears to subside spontaneously in a few days. The disease usually does not affect all of the rearing ponds containing chinook fingerlings, and adjacent ponds are not necessarily infected. No apparent sequence has been observed in the order in which ponds may become infected.

The losses incurred from this disease were originally attributed to a number of causes including diet deficiences, water toxicity, and the inability of the fish to survive the transition from their native spawning areas on the Sacramento River. Subsequent investigations proved, however, that a disease of unknown etiology was contributing to the high mortality rate. At the present time the etiological agent remains unidentified, although experimental laboratory findings indicate that a filterable virus or virus-like agent is responsible for the infection.

Diseases of viral nature are not unknown in fish populations (Watson, 1954); however, this is the first report on the occurrence of a disease of this nature in chinook salmon.

APPEARANCE OF DISEASED FISH

Gross pathology

The gross symptoms of the disease of chi-

[1]Manager, U. S. Fish Cultural Station, (Coleman) Anderson, California.

[2]Dr. E. M. Wood, personal communication.

nook fingerlings at the Coleman hatchery become manifest shortly after the fish begin feeding. Infected fish become lethargic, dark in color, and roll in the water, occasionally swimming in a vertical position. Many fish develop a pop-eyed condition, and in numerous instances a well-defined hemorrhagic area may be seen in the dorsal region posterior to the head. These fish present a distinctive appearance and may easily be observed in the ponds. An anemic condition is generally present which is characterized by pale gills and heart and a light tan-colored liver. As the infected fish do not eat, the stomach appears white and empty while the intestinal tract may contain a white to yellowish colored fluid. The gall bladder contains a green colored fluid in contrast to the light yellowish-green bile usually seen in healthy fish. Often hemorrhagic areas develop at the base of the pelvic fins, on the opercula, isthmus, eye, and in various areas of the musculature. Some mortalities may occur in asymptomatic fish; however, in the majority of mortalities, some or all of the symptoms are noted.

Histopathology

Extensive histopathology is present, with the kidney being most markedly affected. The hemapoetic tissue may be necrotized to the point of being obliterated. In addition, other organs including liver and pancreatic tissue also show necrotic changes. Cytoplasmic and nuclear inclusions of many sizes are found in the various affected organs. A causative agent has never been observed.

EXPERIMENTAL TRANSMISSION

The following experiment was designed to demonstrate the filterability of the disease agent as well as to determine practical methods of handling infected material in future experimental work. Suspensions were prepared by grinding livers and kidneys from infected fish using the following cold sterile diluents: saline, nutrient broth, and distilled water. Each homogenate contained the organs from five fish showing typical symptoms of the disease at Coleman. Each of the three suspensions was divided into a number of aliquots and subjected to various treatments prior to injecting into fish. Penicillin and streptomycin were added to one aliquot from each suspension to give a final concentration of 100 units of each antibiotic per milliliter of inoculum. Equal volumes of the saline suspension were treated with 4 percent NaOH and 2.5N HCl and allowed to remain for 1 hour prior to neutralization. One aliquot from each suspension was subjected to filtration through a bacteria-retaining filter. Millipore, Mandler, and Seitz filters were used for the saline, broth, and distilled-water suspensions, respectively. All material and equipment was kept cool in an ice-water bath throughout the operation. Because there was limited hatchery trough space, aliquots of each suspension could not be treated in an identical manner.

Each of the preparations as well as untreated suspensions were used to inject 20 healthy chinook fingerlings. The untreated, distilled-water suspension was refrigerated for 1 hour prior to injection. The inoculum consisted of 0.5 milliliter of suspension inoculated intraperitoneally. Following inoculation the fish were placed in three inside rearing troughs which had been divided into five compartments each. Controls consisted of three groups of non-inoculated fish as well as one group inoculated with 0.5 milliliter of sterile saline.

BACTERIOLOGICAL EXAMINATION

Aliquots of all filtered inocula were Gram-stained and cultured on various media, anærobically as well as ærobically. No bacteria were seen on the stained preparations and all of the cultures remained sterile.

Material from the dorsal lesions were Gram-stained and also subjected to silver impregnation stains in order to demonstrate spirochætes or other organisms difficult to stain. The lesions were bacteriologically negative by these methods.

RESULTS

Mortalities appeared among the inoculated fish 3 days after injection. Fourteen days from the date of inoculation the majority of compartments, excluding controls, had few or no survivors (Table 1). Only 6 of 80 control fish failed to survive the experiment. No mortalities occurred among one group of non-inoculated controls while the other two groups had one and four mortalities respectively; one control fish injected with sterile saline died during the experiment. None of the fish injected with the NaOH- or HCl-treated ma-

TABLE 1.—*Daily mortalities among groups of 20 chinook salmon fingerlings injected with diseased organs homogenized and suspended in distilled water, saline, or nutrient broth at the Coleman, California, Fish Cultural Station*[1]

Days after inoculation	Distilled-water suspension	Distilled-water suspension[2]	Saline suspension	Saline suspension[2]	Broth suspension	Broth suspension[2]	Millipore filtrate of saline suspension	Mandler filtrate of broth suspension	Seitz filtrate of distilled-water suspension
1	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—
3	6	1	6	4	—	—	—	—	—
4	2	3	6	2	1	3	4	—	—
5	3	1	4	2	8	2	3	2	1
6	2	1	2	1	1	9	3	2	—
7	1	—	1	—	2	1	1	7	—
8	1	3	—	3	1	1	1	3	—
9	1	—	1	1	—	—	3	—	—
10	1	1	—	—	2	2	—	3	—
11	1	3	—	1	—	—	1	1	—
12	—	—	—	—	1	1	—	1	—
13	2	—	—	—	—	1	1	1	—
14	—	—	—	—	—	—	—	—	—
15-24	—	1	—	—	1	—	—	—	—
Total mortalities	20	14	20	14	17	20	17	20	1

[1]Six satisfactory controls, which are not tabulated here, are discussed in the text.
[2]Treated with penicillin and streptomycin.

terials died during the course of the experiment. These fish could be considered as additional controls.

This work substantiated previous findings that a filterable agent was responsible for the high losses experienced at the Coleman Station. In addition, it was shown that although the infective agent may pass through the Millipore and Mandler filters, it is effectively retained by the Seitz filter with the methods used. Penicillin and streptomycin in the concentrations used may have exerted some inhibition to the filterable agent when used in conjunction with saline or distilled water; however, no effect of these antibiotics was noted when used with nutrient broth. It was also shown that the infective agent was able to survive for at least 1 hour in distilled water without any apparent loss in virulence. Sodium hydroxide (4 percent) and hydrochloric acid (2.5N) completely destroyed or neutralized the disease agent.

DISCUSSION

The high losses experienced each year at the Coleman, California, Fish Cultural Station can definitely be attributed to a filterable agent. The exact identity of the organism remains unknown at this time and it may only be speculated that it is of viral nature. As the water temperature at this station rises above 50° F., the mortalities diminish. At this time, however, the fish have also increased in size. The interrelationship of these two factors remains to be investigated. A similar condition exists in cryo-ichtyozoose, the cold-water virus disease of fish which becomes less virulent and disappears as the temperature rises above 60.8° F. (Pacheco and Guimaraes, 1933).

At the Coleman hatchery the disease has affected only those fingerlings that began to feed when the water temperature was below 50° F. If fish are placed in outside rearing ponds when the temperature is above 50° F., the disease does not develop. If, however, infected fish are subjected to temperatures above 50° F., the mortality rate does not appear to be affected. It is obvious that the progeny of spring-run stocks began feeding before other stocks; thus this group of fish is most severely affected. Perhaps the spring-run chinook salmon at Coleman are inherently less resistant to the disease than the later runs. One could also speculate that under natural conditions these fish would not emerge from the gravel until river water temperatures had reached 50° F. or above.

One method by which hatchery management might serve to eliminate or reduce the disease would be to retard the development of the eggs and fry by rearing them in colder water. This procedure would allow the river water to reach a temperature of 50° F. prior to the time the fry are put out to feed.

It is strongly suspected that the infective

agent is endemic in the water supply. It has been fairly well substantiated that the etiologic agent is not necessarily present in salmon products used as food since the infection appeared during one rearing season even though beef liver had been used as the sole source of food.

This disease has become a significant problem in hatchery management at the Coleman Fish Cultural Station. By a better understanding of the etiology it may be possible to modify existing fish cultural procedures so that mortalities may be reduced or eliminated. Further investigations are being conducted on the epidemiology of the disease and characteristics of the pathogenic agent.

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Narcotization of Chinook Salmon Fingerlings with Tricaine Methanesulfonate (M.S. 222)[1]

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ABSTRACT

Chinook salmon fingerlings were exposed to varying concentrations of tricaine methanesulfonate (M.S. 222) for a period of 5 minutes. Groups exposed to concentrations of 1:10,000 and greater experienced heavy mortality. Concentrations of 1:50,000 and less proved ineffective for narcotizing purposes. Experimental evidence indicates that the lowest concentration of the drug capable of narcotizing the test animals within the allotted time period is 1:33,000. Fingerlings can withstand this dose (1:33,000) for at least 105 minutes without ill effects but an immersion approaching 241 minutes is fatal. Fingerlings adapted to either a salt-water environment of 52° F. or to a fresh-water environment of 59° F. were narcotized with equal facility. During a 2-week observation period following recovery, no latent effects of narcotization were noted in any test animal.

INTRODUCTION

The use of anesthetics to immobilize fish for marking, measuring, and weighing purposes has increased markedly during recent years. Many different drugs have been tested, but at present tricaine methanesulfonate (M.S. 222) is used extensively. A review of the literature indicates that 14 species of fish have been treated with M.S. 222. Table 1 presents the salient features of each investigation and shows that the effectiveness of the drug varies with concentration, immersion time, species, size of fish, and water temperature. When it became necessary to anesthetize chinook salmon fingerlings *(Oncorhynchus tshawytscha)* during the course of an experiment, several questions arose that could not be answered on the basis of available information.

It was the objective of this study to prepare a concentration of M.S. 222 (1) that will narcotize salmon fingerlings within 5 minutes, (2) that fingerlings can withstand for extended periods, and (3) that has no latent effects such as mortality or loss of appetite.

METHODS AND MATERIALS

All test animals were progeny of a single pair of chinook salmon. At the time of the study the average fingerling measured 3.5 inches (89 millimeters) in standard length and weighed 1/60 of a pound (7.6 grams). In the first experiment, varying aliquots of a stock solution of M.S. 222 were added to stainless-steel containers of 3-quart capacity. A wide range of concentrations (Table 2) was obtained when the solutions were diluted with lake water to a volume of 2 quarts. Containers and contents were placed in a constant (59° F.) temperature bath. Test fingerlings did not have to become adapted to this temperature as it was identical to that of their previous environment. Five fingerlings were placed in each container for a period of 5 minutes, after which time the fingerlings were removed and permitted to recover in a trough filled with running lake water (59° F.). The exposure time of 5 minutes was imposed at all concentrations regardless of the condition of the fish during this period. The following information was recorded: mortality, number completely narcotized, time for complete narcosis, and recovery time. A fish was considered narcotized when it lay on its side at the bottom of the container without moving any part of its body except perhaps the gill covers. Recovery was considered complete as soon as a fish was able to maintain a normal swimming position. Time for complete narcosis refers to the last fish narcotized; similarly, recovery time refers to the last fingerling to recover.

In a second experiment, each group of five fingerlings was exposed to an M.S. 222 concentration of 1:33,000 for varying time intervals (Table 3). Data regarding mortality and recovery time were recorded. Other experi-

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TABLE 1.—*Summary of the effects of M.S. 222 on fish, as reported by various authors*

Species	Size	Concentration of M.S. 222	Length of time to narcotize	Total time in M.S. 222 solution	Water temperature	Recovery time	Mortality	Authority
Carassius auratus	—[1]	1:1,000	2 minutes	—	—	30-60 minutes	—	As quoted in Meister and Ritzi (1958)
	—	1:20,000	30-60 minutes	—	61° F.	—	—	
	—	1:20,000	30-60 minutes	24 hours	61° F.	2 hours	—	
	—	1:20,000	Ineffective	—	>61° F.			
Cristivomer namaycush	—	1:12,000	—	—	35-68° F.	—	None	Meister and Ritzi (1958)
	Adults	1:12,500	—	—	—	—	None	As quoted in Meister and Ritzi (1958)
Lepomis macrochirus	—	1:10,000	—	—	50-80° F.	—	—	As quoted in Wood (1956)
	—	1:40,000	Ineffective	—	50-80° F.	—	—	
Micropterus salmoides	—	1:3,333	30-45 seconds	30-45 sec.	68-69.8° F.	Less than 10 minutes	None	Fromm (1958)
Notemigonus crysoleucas	—	1:10,000	—	—	50-80° F.	—	—	As quoted in Wood (1956)
Oncorhynchus kisutch	Fingerlings	1:12,500	Several minutes	—	55-63° F.	—	None	Nelson (1953)
O. nerka	Fingerlings	1:10,000	—	—	55-63° F.	—	100 percent	Nelson (1953)
O. tshawytscha	1,077 to pound	1:7,500	—	—	—	—	Negligible	Johnson and Shelton (1958)
	3.8-5.4 inches in total length	1:25,000	—	—	—	—	—	Robertson (1957)
Pimephales promelas	—	1:10,000	—	—	50-80° F.	—	100 percent	As quoted in Wood (1956)
Salmo clarki	1,200 to pound	1:20,000	—	5 hours	About 40° F.	1 hour	95 percent	Thompson (1959)
	"	1:40,000	—	"	"	"	Negligible	
	"	1:60,000	—	"	"	"	"	
	"	1:80,000	—	"	"	"	"	
	"	1:120,000	—	"	"	"	"	
	3,000 to pound	1:40,000	—	3 hours	About 40° F.	About 1 hour	1 percent	Thompson (1959)
Salmo gairdneri	Large Spawning adults	1:7,570	30 seconds	3 minutes	50° F.	—	—	Butler (1957)
		1:3,787	30-45 seconds	30-45 seconds	43° F.	—	Some—if kept longer in solution	Parkhurst and Smith (1957)
Salmo salar	—	1:12,000	—	—	35-68° F.	—	None	Meister and Ritzi (1958)
Salvelinus fontinalis	5.3-10.3 inches total length	1:5,000 to 1:20,000	2.5-13.5 min.	10 min.+ time to anesthetize	37-39° F.	2-6 min.	None	Meister and Ritzi (1958)
	"	1:5,000 to 1:25,000	1.0-5.2 min.	10 min.+ time to anesthetize	48-51° F.	2-6 min.	None	
Salvelinus fontinalis X *C. namaycush* (hybrid)	0.5 to 4.5 pounds	1:8,000	—	8 min.+ time to anesthetize	33.8° to 50° F.	—	100 percent	Martin and Scott (1959)
	"	1:16,000	—		"	—	—	
	"	1:24,000	—		"	—		
	"	1:32,000	Ineffective		"	—		
Salvelinus malma	Fingerlings	1:12,500	—	—	55-63° F.	—	Negligible	Nelson (1953)
		1:10,000	—	—	"	—	100 percent	

[1]Dash indicates information not available.

mental conditions were the same as those previously described.

The third experiment was conducted in salt water at 52° F. and involved 150 actively feeding fingerlings living in a salt-water (52° F.) environment for the previous 26 days in a tank located at the College of Fisheries. The fingerlings were exposed to a 1:33,000 salt-water dilution of the drug for 5 to 15 minutes, measured, and then returned to their aquarium. Experiments regarding the effects of varying concentrations and immersion times on marine-adapted fingerlings were not undertaken. These fish were essential to the execution of a future study and therefore nonexpendable. As with the salt-water group, the same concentration of the drug (1:33,000)

was applied to 150 fingerlings still adapted to a fresh-water (59° F.) habitat. The fish were immersed for 5 to 15 minutes, measured, and returned to their aquarium; however, narcotization and subsequent recovery of these fingerlings occurred in a fresh-water (59° F.) medium.

During the course of the study no fish was used more than once. All fingerlings were observed for a period of 2 weeks following narcotization in order to detect any latent effects such as mortality or poor appetite.

EXPERIMENTAL RESULTS

The findings on the effects of varying concentrations of M.S. 222 on chinook salmon fingerlings are presented in Table 2. Solutions of 1:100,000 and 1:50,000 did not completely narcotize fish within the allotted time of 5 minutes; however, symptoms of intoxication, manifested by difficulty in maintaining a normal swimming position, were evident in these groups. A concentration of 1:10,000 killed two of the five fish while the next higher dose (1:8,300) killed the entire group. It is of some interest that concentrations greater than 1:10,000 have been utilized so frequently (Table 1). For example, Johnson and Shelton (1958) successfully used a 1:7,500 solution on chinook salmon fry but did not mention the amount of time the fry were exposed to the anesthetic (presumably less than 1 minute). The results of the present investigation suggest that the procedure employed by Johnson and Shelton is critically dependent upon the length of the exposure period.

Time for complete narcosis appears to be directly related to concentration whereas the recovery time does not exhibit as obvious a trend (possibly due to the short immersion time). At concentrations above 1:14,800 some or all of the fish died. From 1:14,800 down to a concentration of 1:33,000 narcosis was complete in less than 5 minutes. In view of the demonstrated lethal effects of high dosages, the lower concentration is recommended for narcotizing purposes.

TABLE 2.—*Observations on narcotization of chinook salmon fingerlings with M.S. 222 with constant immersion time (5 minutes) at various concentrations*

Concentration	Mortality (five-fish sample)	Number completely narcotized	Time for complete narcosis (minutes)	Recovery time (minutes)
0 (Control)	0	0	—	0.0
1:100,000	0	0	—	0.5
1: 50,000	0	0	—	2.0
1: 33,000	0	5	4.8	1.0
1: 25,000	0	5	3.3	2.4
1: 20,000	0	5	1.7	2.0
1: 14,800	0	5	1.6	4.1
1: 10,000	2	5	0.5	—
1: 8,300	5	5	0.6	—
1: 2,650	5	5	0.3	—

The results of immersing groups of fingerlings in a 1:33,000 concentration of M.S. 222 for varying lengths of time are summarized in Table 3. These data indicate that fingerlings can withstand a concentration of 1:33,000 for at least 105 minutes without experiencing mortality; however, an immersion approaching 241 minutes is fatal. It should be mentioned at this point that water æration was not employed in any of the test containers at any time; consequently, death would have been expedited if all available oxygen was utilized.

TABLE 3.—*Observations on narcotization of chinook salmon fingerlings with M.S. 222 at constant concentration (1:33,000) with variable immersion times*

Immersion time (minutes)	Mortality (five-fish sample)	Recovery time (minutes)
7.5	0	1.6
15	0	3.7
30	0	4.5
65	0	3.8
105	0	2.0
241	5	—
246	5	—

Long exposure to M.S. 222 produces deep narcosis, as evidenced by the apparent cessation of respiratory movements. This phenomenon was also observed by Meister and Ritzi (1958) while anesthetizing brook trout in a 1:1,000 concentration. Table 3 shows that recovery time and immersion are directly related up to a period of 30 minutes, after which interval the recovery time decreases. Since the mechanism by which this drug affects fish has not been determined, this anomaly may have physiological significance.

Fingerlings that were adapted to a salt-water (52° F.) environment as well as the 150 fingerlings still adapted to a fresh-water (59° F.) environment were successfully narcotized within 5 minutes by a 1:33,000 concentration of M.S. 222. Some fingerlings were exposed to the drug for as long as 15 minutes but no harmful aftereffects were noted.

A. C. Hartt[3] has narcotized all five species of Pacific salmon as well as steelhead trout during the course of tagging experiments on the high seas. At a temperature of 51° F. a total of 496 salmonoids, ranging in size from 6.5 to 23.2 inches, were immobilized within 30 seconds by M.S. 222 at a concentration of 1:4,000. Hartt notes that recovery occurred within 2 minutes without apparent injury or damage.

Fingerlings that had successfully recuperated from narcosis (all experiments) were observed during the following 2 weeks. No appetite loss was observed; in fact, the fish fed voraciously within 1 hour after recovery. No mortality occurred during the observation period, and all fish appeared to have recovered completely.

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Factors Influencing Production of Immature Cutthroat Trout in Arnica Creek, Yellowstone Park

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ABSTRACT

Data are presented on the variations in production of immature cutthroat trout from Arnica Creek, a tributary of Yellowstone Lake, from 1951 to 1958. Of 36,786 immature trout counted, 87.3 percent were age-group 0. The highest production occurred during years when large numbers of age-group 0 trout migrated downstream to Yellowstone Lake from mid-July to mid-August, or soon after they emerged from the gravel. Ecological conditions associated with a large July-August migration were receding water levels and much light. High populations of age-group I and II trout in Arnica Creek, which are predacious on fry, did not appear to have as much influence on the production of good year classes as did the downstream migration pattern. No relationship between year-class variation of immatures and reappearance of these same year classes in the spawning runs was evident. The number of spawners or the time of the spawning run did not bear any consistent relationship to the production of immatures.

INTRODUCTION

Several studies have been published on the biology of the cutthroat trout *(Salmo clarki lewisi)* in tributary streams of Yellowstone Lake (Welsh, 1952[1]; Ball, 1955; Cope, 1956, 1957; Ball and Cope, manuscript[2]). These papers include information on mortality rates, migration patterns, choice of spawning sites, and homing instincts. The present paper offers additional data on immature trout biology and discusses factors which influenced year-to-year variations in production of immature cutthroat trout in Arnica Creek. The relationship of these variations to the reappearance of these same year classes in the spawning runs in Arnica Creek is briefly treated. Field studies were carried on from 1950 to 1958 by personnel of the Rocky Mountain Sport Fishery Investigations.

CUTTHROAT TROUT BIOLOGY

Cutthroat trout, principally age-group IV and V, migrate into streams tributary to Yellowstone Lake from May through July to spawn, and the eggs are deposited in the gravel. From 30 to 60 percent of the adult spawners die after spawning and the survivors move back into Yellowstone Lake within a few weeks after spawning. Fry emerge from the gravel about 30 days after egg deposition and congregate in shallow water areas of the streams. Some immature trout migrate to the lake a short time after emergence from the gravel, while others remain in the streams for periods up to 2 years. The largest number leave the streams by the first of October of the first year. Predation and other factors cause an estimated average mortality of 99.6 percent from the time of egg deposition to the time when fry and fingerlings return to the lake. Tagging studies on immature and adult trout have shown definite homing tendencies. Mortality studies have suggested a survival rate of 36 percent from the time that immatures leave the stream until they return as spawners. Most of the trout taken in the sport fishery are trout in age-groups III, IV, and V.

METHODS

All data in this report were collected from Arnica Creek, which is 4 miles long and has excellent spawning gravel its entire length. A two-way fish trap was operated on this stream from 1950 through 1958. It was originally about 50 yards from the stream mouth but was moved 250 yards upstream in the fall of 1951. Counts from 1952 to 1958 are from the upstream site. This trap was put in op-

[1]Welsh, James P. (1952) A population study of Yellowstone black-spotted trout *(Salmo clarki lewisi* Girard). Ph.D. dissertation, Leland Stanford Jr. U., 180 pp.

[2]Ball, Orville P., and Oliver B. Cope. Manuscript. Mortality studies of cutthroat trout in Yellowstone Lake.

eration each year during the first part of May and was dismantled at different dates from August 31 to October 6. All upstream spawners were marked, and the number of spawners that migrated prior to the installation of the trap or when the trap was not functioning was calculated from the numbers of marked and unmarked downstream migrants.

A fine-mesh screen was installed at the trap during late June or early July of each year, which permitted counts of all fry and fingerlings migrating downstream. It is assumed from the fact that no immature fish were captured in the upstream trap that those captured in the downstream trap were migrants on their way to Yellowstone Lake and not those which were indiscriminately moving up and downstream. Each day a maximum of 50 immature fish from the downstream run were measured to the nearest millimeter. They were separated into three length groups which closely followed age-group O, I, and II. The first group included recently emerged fry which were less than 45 millimeters in length during July and early August, but some of which reached 70 millimeters in September. The second group included age-group I fish which were about 55 millimeters in June but reached 150 millimeters in September. The last group were over 130 millimeters in June and up to 200 millimeters long in September. Spent spawners migrating downstream were over 275 millimeters in length and could be easily distinguished by their emaciated condition. During some years a visual count was made of all fish left in the stream when the trap was dismantled.

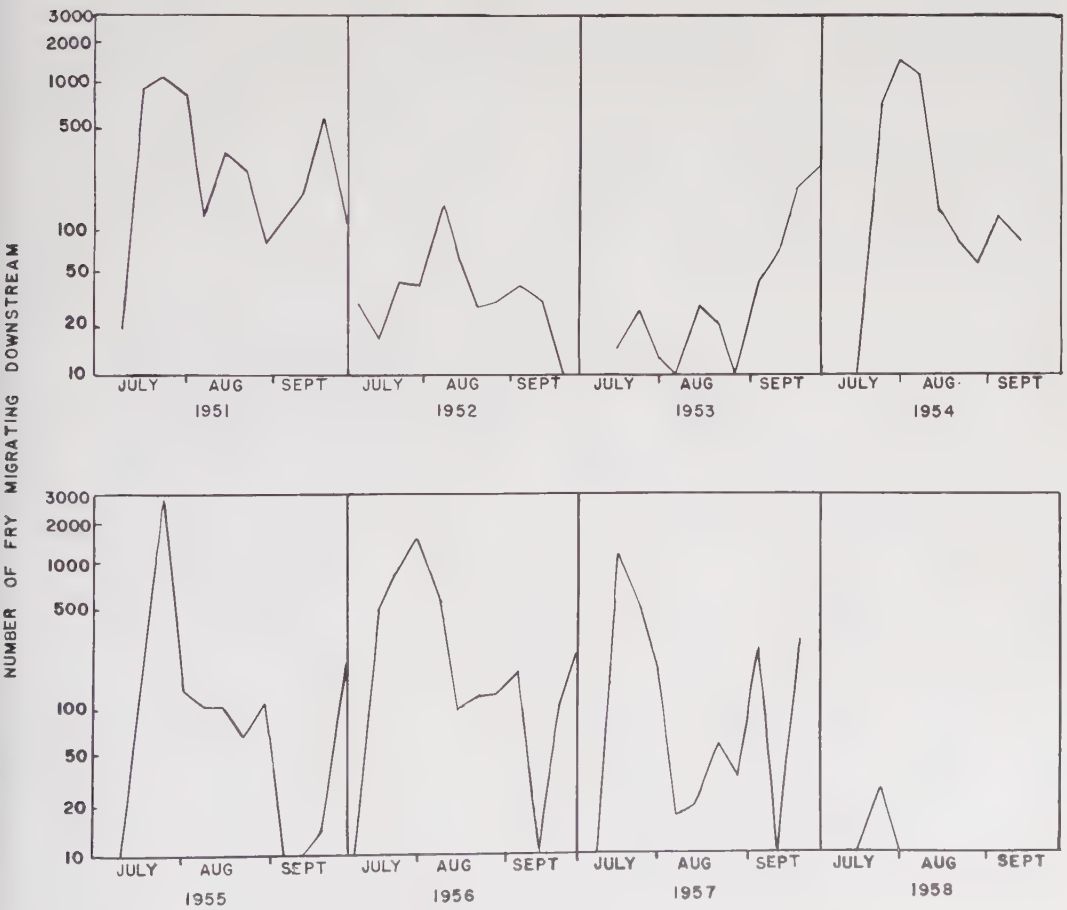

FIGURE 1.—Numbers of downstream-migrating fry counted at Arnica Creek trap expressed as logarithms of weekly totals from 1951 to 1958.

Water temperatures at the trap were measured with a recording thermograph. Stream flow from 1951 to 1958 was determined by measuring water depth on a staff gauge 200 yards upstream from the trap. Readings were usually taken once a day. Weather conditions recorded hourly by creel census clerks during each census day on Yellowstone Lake have been assumed to apply to Arnica Creek. Conditions were recorded in general terms such as rainy, cloudy, clear, etc., and have been interpreted to represent the amount of light present. Fry are considered as age-group O trout.

DOWNSTREAM MIGRATION OF IMMATURE TROUT

Mortality rates during various life history stages of immature cutthroat trout in Arnica Creek have been treated by Ball and Cope (in preparation) for data through 1953. The present study is concerned only with the number of immatures that passed through the Arnica Creek trap or were left in the stream after the trap was dismantled. The juvenile trout that were counted from 1950 to 1958 consisted of age-group O, I, and II (Table 1). Of a total of 36,786 fish counted, 87.3 percent were age-group O, 10.9 percent age-group I, and 1.8 percent age-group II. In 1952, 1953, and 1958 the total number of immatures produced was low. The number of age-group I and II trout exceeded the number of age-group O trout in 1952.

Downstream migration patterns of fry from 1951 to 1958 showed that there were usually two peaks of movement (Figure 1). The first and larger migration occurred from the middle of July to the middle of August and included small fry (20 to 35 millimeters) that had recently emerged from the gravel. Smith (1947) recorded a similar immediate downstream movement of recently emerged Lahontan cutthroat trout fry in Convict Creek, California. Another large downstream migration usually occurred in Arnica Creek in September when the fry were over 40 millimeters in total length. The data for 1954 and 1958 did not show this September peak because the trap was dismantled early in these years. A large number of fry were left in the stream, however, and many of them probably went to Yellowstone Lake during September.

There were no downstream migrations during July and August in 1953 and 1958 and only a small run in 1952. The July-August migration is important for computation of the total years' production of fry because 77.5 percent of the age-group O trout counted at the trap moved downstream during this period.

The downstream migrants which were measured at the trap showed increased lengths throughout the season (Table 2). There were no relationships, however, between the seasonal differences in downstream migration patterns and lengths of fry. The sizes of fish measured during the years of 1952, 1953, and 1958, when few fish moved downstream, were not different from those in the years when the large July-August movements occurred.

Shapovalov and Taft (1954) and other investigators have mentioned the possibility of migration size influencing downstream migrations of immature salmonids. This concept means that immatures must reach a certain size before they migrate downstream. It would infer that those fry which emerged earliest and grew the fastest would migrate first. Although length measurements of fry in the stream above the trap are not available, observed stream temperatures and movement of

TABLE 1.—*Number of immature trout trapped in Arnica Creek annually, 1950-1958, and number remaining in Creek after trap was removed*[1]*—expressed as total number in each age group*

Year	Date trap removed	Age-group O		Age-group I		Age-group II		Total		Grand total
		Trapped	In stream	Trapped	In stream	Trapped	In stream	Trapped	In stream	
1950[2]	September 28	9,556	—	300	—	95	—	9,951	—	9,951
1951[2]	October 6	5,240	—	365	—	39	—	5,644	—	5,644
1952	September 21	502	—	792	—	242	—	1,536	—	1,536
1953	September 28	1,332	708	763	407	82	67	2,177	1,182	3,359
1954	September 14	4,151	—	943	—	47	—	5,141	—	5,141
1955	September 24	4,182	244	340	15	7	0	4,529	259	4,788
1956	September 13	4,268	612	386	56	132	5	4,786	673	5,459
1957	September 25	2,850	405	121	270	5	3	2,976	678	3,654
1958	August 31	36	1,950	9	30	1	15	46	1,995	2,041

[1]Data not available on number of fish in stream after dismantling of trap for 1950, 1951, 1952, and 1954.
[2]Data from Welsh (1952).

TABLE 2.—*Mean total lengths in millimeters of cutthroat trout fry migrating downstream, expressed by weekly periods—1951 to 1958*

Date	Year							
	1951	1952	1953	1954	1955	1956	1957	1958
July 7-13	25.8	26.8	—	26.4	25.0	—	26.5	—
July 14-20	26.3	27.9	29.2	24.8	24.2	28.5	26.8	—
July 21-27	31.1	35.7	26.3	27.5	24.1	25.4	27.1	27.0
July 28-August 3	32.8	38.1	26.4	28.1	24.8	25.2	31.3	31.0
August 4-10	33.4	51.3	36.7	31.7	28.4	27.1	48.7	0
August 11-17	37.1	49.4	41.5	39.2	39.4	29.3	53.0	22.3
August 18-24	43.9	54.3	47.2	46.1	43.0	33.7	62.3	0
August 25-31	44.9	55.5	55.6	44.5	47.4	42.2	65.8	54.4
September 1-7	45.3	60.3	50.3	52.3	—	41.3	54.5	—
September 8-14	44.3	68.4	47.8	50.4	—	—	62.2	—
September 15-21	49.2	65.5	53.5	—	—	—	—	—
September 22-28	48.1	—	60.8	—	—	—	—	—

spawners make it unlikely that growth rates of fry or times of emergence varied as much as the migration pattern. Low July-August migrations in 1953 and 1958, therefore, did not appear to be caused by slow growth and/or late emergence.

Some immatures spent one or two winters in Arnica Creek before they entered Yellowstone Lake. The downstream migration of the age-groups I and II occurred from June to September, but the greatest number passed through the trap during June and July or prior to the major downstream migration of age-group 0 trout (Table 3). There is some evidence that upstream movement of age-group I and II trout occurred either before the trap was in operation or after the trap was dismantled, since the number of fish in these groups counted downstream in 1956 was much larger than the number observed in the stream after the trap was dismantled in 1955. This movement was demonstrated to a lesser degree by the number counted downstream in 1954 and the lower number observed in the fall of 1953, but the visual counts in the stream after the trap was dismantled were subjected to error.

SPAWNING MIGRATIONS

The spawning runs in Arnica Creek from 1951 to 1958 varied from 3,523 in 1952 to 6,200 in 1954 (Table 4) and showed no consistent relationships to the production of immatures. Ball and Cope[3] also noted a lack of correlation.

[3]See footnote 2.

TABLE 3.—*Number of age-group I and II cutthroat trout counted at downstream trap at Arnica Creek from 1951 to 1958*

Periods	Year															
	1951		1952		1953		1954		1955		1956		1957		1958	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
May 15-June 30	2	0	135	97	75	39	132	0	29	7	18	38	2	2	0	0
July 1-6	25	11	38	14	13	2	421	0	6	0	95	59	0	3	1	0
July 7-13	64	5	153	51	191	0	103	20	1	0	109	18	3	0	0	1
July 14-20	47	3	34	8	266	0	49	16	1	0	135	15	2	0	0	0
July 21-27	100	1	30	10	32	1	63	0	0	0	5	0	3	0	0	0
July 28-August 3	21	10	66	13	15	12	134	6	0	0	7	2	27	0	3	0
August 4-10	17	6	93	15	11	0	11	0	0	0	4	0	3	0	0	0
August 11-17	16	1	72	13	6	0	10	1	0	0	0	0	3	0	1	0
August 18-24	2	2	18	0	9	0	10	0	0	0	1	0	25	0	2	0
August 25-31	4	0	29	2	10	2	0	0	0	0	0	0	2	0	2	0
September 1-7	5	0	16	1	19	3	10	4	0	0	0	0	24	0		
September 8-14	22	0	82	15	20	14	0	0	0	0	0	0	0	0		
September 15-21	29	0	26	3	22	1	0	0	0	0	12	0	27	0		
September 22-28	11	0	—	—	74	8	—	—	303	0	—	-	—	—		
Number observed in stream	[1]	[1]	[1]	[1]	407	67	[1]	[1]	15	0	56	5	195	200	30	15
Total	365	39	792	242	1,170	149	943	47	355	7	442	137	316	205	39	16
Total both groups	404		1,034		1,319		990		362		579		521		55	

[1]Number in stream not available.

TABLE 4.—*Number of spawning adults counted from trap and calculated[1] number of upstream migrants in Arnica Creek—expressed as totals in bi-weekly periods*

Period	Year							
	1951	1952	1953	1954	1955	1956	1957	1958
May 4-17	[2]	[2]	400	[2]	53	92	59	428
May 18-31	1,028	1,103	941	309	835	97	205	1,517
June 1-14	871	1,042	1,312	2,271	1,771	1,492	1,047	1,241
June 15-28	640	606	763	567	331	126	562	492
June 29-July 12	578	392	690	52	230	3	137	93
July 13-26	277	155	178	357	26	5	60	24
July 27-August 9	105	16	55	113	0	0	14	3
Total counted	3,499	3,314	4,339	3,669	3,246	1,815	2,084	3,798
Number calculated	1,256	209	125	2,531	1,454	2,097	1,734	243
Total run	4,755	3,523	4,464	6,200	4,700	3,912	3,818	4,041

[1]Numbers calculated when trap not in operation or functioning inefficiently.
[2]Trap not in operation.

ECOLOGICAL FACTORS AND PRODUCTION OF IMMATURES

From 1951 to 1958, 77.5 percent of the fry counted at Arnica Creek trap were those which passed through the trap from July 15 to August 15, soon after they emerged from the gravel. During the years 1952, 1953, and 1958 a low total number of immatures passed through the Arnica Creek trap, with almost no July-August migrations.

Maximum and mean water temperatures did not show any changes that could be related definitely to numbers of fry migrating downstream (Table 5). The periods from July 14 to August 17, when the majority of the fry moved downstream, were not consistently different in 1952, 1953, and 1958 when few migrated downstream, from the other years of the study.

Information on water levels in Arnica Creek is not complete, but the available data suggest that receding water levels throughout the summer were associated with a high July-August downstream migration of fry (Table 6). During 1953 and 1958, when few fry moved downstream, the water levels were more stable than during 1954, 1955, 1956, or 1957. The actual volume of water in the stream does not seem to be important since water levels in 1956 and 1957 were much higher than in other years, those in 1954 and 1955 were low, and all these years showed similar migration patterns. Shapovalov and Taft (1954) stated that low water flow was associated with the downstream migration pattern of steelhead, but receding water levels appeared to be more important for cutthroat trout in Arnica Creek.

Receding water levels are probably an important cause of downstream movement because there is a continuous reduction of shallow water habitat where fry are found. The fry had less reason to leave the stream when the shallow water area remained relatively stable, as in 1953 and 1958.

TABLE 5.—*Mean and maximum water temperatures in degrees Fahrenheit in Arnica Creek by weekly periods from 1951 to 1958*

Weekly period and item	Year							
	1951	1952	1953	1954	1955	1956	1957	1958
July 14-20 Maximum	68	67	70	71	75	65	68	68
Mean	60	58	62	63	66	56	58	57[1]
July 21-27 Maximum	68	67	69	70	72	63	68	69
Mean	59	59	60	60	64	58	59	58
July 28-August 3 Maximum	66[1]	67	69	69	72[1]	64	68	70
Mean	59[1]	58	60	61[1]	63	57	59	59
August 4-10 Maximum	64[1]	66	68	67	72	61	68	70
Mean	56[1]	58	58	59	63	54	58	59
August 11-17 Maximum	65	—	66	66	70	62	—	70
Mean	58	—	58	59	63	56	—	61

[1]Temperature data not complete.

TABLE 6.—*Mean weekly water levels at Arnica Creek gauging station from 1952 to 1958—expressed in inches*

Period	Year						
	1952	1953	1954	1955	1956	1957	1958
June							
3-9	22.5	15.4	20.6	20.4	31.1	25.4	19.8
10-16	19.6	—	24.2	20.1	27.9	23.4	19.1
17-23	18.2	—	19.9	17.2	24.7	21.9	18.7
24-30	20.5	16.7	18.6	16.1	22.5	20.5	18.6
July							
1-6	12.5	16.1	17.2	15.9	22.8	19.3	17.2
7-13	—	16.2	16.2	15.5	21.4	19.2	17.0
14-20	—	15.6	16.8	15.8	20.7	19.0	17.3
21-27	—	15.5	15.9	15.8	20.3	18.5	17.0
July 28-August 3	—	15.7	15.1	14.9	20.7	18.2	17.0
August							
4-10	—	15.4	15.3	14.9	—	17.9	16.7
11-17	—	—	15.1	14.7	—	17.8	17.0
18-24	—	15.5	15.0	14.5	—	17.0	16.7
25-31	—	15.2	—	14.8	—	15.5	17.0

The amount of light present from July 15 to August 15 appeared to be associated with the migration of cutthroat trout fry. During 1953 and 1958, when there were more days with much rain and cloudy weather and subdued light than in other years, there was a small, early migration (Table 7). The importance of light in influencing the downstream migration of fry has not been clearly demonstrated in the present study, but Fields (1957) summarized other studies and showed the importance of light in salmonid fry migration. Cope (1956) interpreted the nocturnal downstream migration pattern of fry in Arnica Creek as indicative of negative phototropism. Fields (1957) found that the steelhead trout was more sensitive to light than any of the Pacific salmons and that normal response of young salmon and trout was negative. Hoar (1954) showed that sockeyes selected cover in relation to light, and he postulated that downstream migrations were related to low light intensities. In Arnica Creek the lower light intensities in 1953 and 1958 may have been responsible for keeping the fry in the stream.

Gill netting in Yellowstone Lake showed that cutthroat trout less than 200 millimeters long frequented deeper waters in the summer of 1957 (relatively clear) than in 1958 (relatively cloudy). In 1957, 16 overnight experimental gill-net sets between depths of 50 and 100 feet showed an average catch of 1.56 trout; in 1958, 29 overnight sets, at the same depth range, had an average catch of 0.58 trout. Temperature differences in the lake were not associated with these variations. There is evidence, therefore, that light influences both the depth distribution of trout in the lake and the migration patterns in the stream.

The conditions of stable water levels and cloudy weather were closely related, since summer rains were associated with both conditions. It was not possible to determine which factor was more important from the information collected.

RELATIONSHIP OF ABUNDANCE OF AGE-GROUP I AND II TO FRY PRODUCTION

Welsh (1952)[4] demonstrated heavy predation on cutthroat trout fry by age-group I and II trout in Arnica Creek. He examined 57 trout in these latter age groups and found 176 fry in 39 stomachs. In 1952 and 1953 a low production of fry was coincident with a high population of age-group I and II trout. In 1955, 1956, and 1957, however, large numbers of age-group I and II trout were in the stream and a large production of fry resulted from a high July-August downstream migration. It appeared, therefore, that the down-

[4]See footnote 1.

TABLE 7.—*Weather from July 15 to August 15 at Yellowstone Lake, 1951-1958*[1]*—expressed as percentage of days with various conditions*

Year	Number of days	Clear	Occasional clouds[2]	Occasional clouds and rain[3]	Continued cloudy	Cloudy, rain	Continued rain
1951	32	59.4	3.1	25.0	6.1	3.1	3.1
1952	28	64.3	3.6	21.4	10.7	0	0
1953	25	56.0	16.0	12.0	4.0	12.0	0
1954	29	69.0	0	31.0	0	0	0
1955	27	59.3	11.1	29.6	0	0	0
1956	28	42.9	14.3	32.1	0	7.1	3.6
1957	31	83.9	0	12.9	0	3.2	0
1958	29	41.4	13.8	17.2	0	17.2	10.3

[1]Data from creel-census records.
[2]Clouds lasting only a few hours.
[3]Clouds lasting less than 2 hours and showers lasting less than 15 minutes for entire day.

stream migration pattern of fry is of greater importance in producing a strong year class than a low number of age-group I and II fish in the stream, since several good downstream migrations were produced in the presence of many age-group I and II fish.

SURVIVAL OF IMMATURE TROUT IN YELLOWSTONE LAKE

There are few good data on the survival rates of different sizes of immature trout after they enter Yellowstone Lake. Ball (1955) showed that of 644 fin-clipped immatures returned from Arnica Creek, 21.5 percent were from the 51- to 99-millimeter group, while 15.8 percent were from the 41- to 140-millimeter group. Many studies have shown a positive correlation between the size of trout planted in a lake and the survival rate, and such a relationship may exist in Yellowstone Lake. The results from Arnica Creek suggest, however, that a larger year class would be formed if the immatures entered the lake soon after emergence, even though they would be smaller than those that migrated at a later time. In the lake they would not be subjected to the heavy predation and competition that they would experience in the stream. The rate of predation from age-group I and II trout in Arnica Creek is much higher than the rate of predation in Yellowstone Lake. A total of 694 cutthroat trout stomachs were examined from the lake, and only five contained trout. Limnological studies have also demonstrated an abundance of other food in the lake. A possible higher survival rate for larger immatures entering the lake, therefore, would be considerably overshadowed by the low number that would survive the predation and other competition in the stream. Evidence from fish caught by anglers also showed that trout which overwinter in streams make up a small percentage of the catch. Laakso and Cope (1956) found that the scales from only 9 out of 1,300 fish caught by anglers at Fishing Bridge and West Thumb from 1951 to 1953 possessed the stream nucleus which is typical of cutthroat trout that overwinter in streams.

RETURN OF YEAR CLASSES TO SPAWNING RUNS

The present study has shown annual variations in the production of immature trout from Arnica Creek. Since trout from this stream show a definite homing behavior (Ball, 1955), we can assume that most immatures produced in Arnica Creek will return as spawners if they survive. The strength of the different year classes in the spawning runs does not show the great variations that might be expected from the numbers of immatures migrating downstream (Table 8). The year classes of 1951 and 1952 appeared stronger than that of 1950 in the spawning runs, while the number of immatures in 1950 indicated a strong year class. The 1953 year class was low on the basis of immatures, but the number of spawners of this class was not unusually low.

There is a substantial difference in the estimates of year-class strength made from immature fish and subsequent spawning runs (Table 8). In certain year classes, such as 1952 and 1953, the strength from production of immatures was far less than that indicated when the same year class returned as spawners, although Ball and Cope[5] mentioned that 1.22 percent of the fish in the spawning runs were repeat spawners. The cause for this error of estimate may be due to the fact that much spawning takes place below the fish trap, and the survival rate of these fish is probably higher because there is a smaller number of age-group I and II trout in this

[5]See footnote 2.

TABLE 8.—*Estimated numbers of immature trout in the 1950-1954 year classes and number of spawners from these classes returning in 1953-1959*

[Parentheses show number of fish aged]

Year class	Number of immatures	Year of spawning run							Total spawners
		1953 (207)	1954 (197)	1955 (309)	1956 (163)	1957 (339)	1958 (91)	1959 (110)	
1950	10,163	502	2,327	1,354	98	—	—	—	4,281
1951	6,181	—	712	2,866	1,248	91	44	—	4,961
1952	1,719	—	—	395	2,183	2,048	358	—	4,984
1953	2,990	—	—	—	383	1,563	2,352	16	4,314
1954	4,643	—	—	—	—	—	1,289	565	1,854

section of the stream (Welsh, 1952)[6]. This possibility is further substantiated by the fact that trap counts in 1950 and 1951 were appreciably higher than in later years because the trap was moved 250 yards upstream in the fall of 1951. The year-class estimate from returning spawners did not show any relationship to estimates of the same year class from immature production.

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[6]See footnote 1.

Selectivity of Gill Nets for Lake Whitefish, *Coregonus clupeaformis*

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ABSTRACT

The methods by which the curve of gill-net selectivity has been determined by various workers are discussed. An empirical demonstration of the applicability of the normal curve of probability to the distribution of size classes of lake whitefish *(Coregonus clupeaformis)* in catches from experimental gangs of gill nets fished in South Bay, Lake Huron, from 1954 to 1958 is presented. A plot was made of the numbers of fish caught in each length class against the logarithms of the ratios of the girth of the fish to the perimeter of the mesh. An adjustment was made to allow for the presence of unequal numbers of the various length classes in the population fished. The curves for all length classes concerned when superimposed were found to be essentially the same and could be described by the normal frequency distribution with the mode at 0.100 and a standard deviation of $\pm$ 0.0514, expressed as logarithms of fish girth to mesh perimeter. The efficiencies of nylon and cotton nets are discussed on the basis of the literature and of experiments in which gangs with alternate cotton and nylon nets were fished in South Bay. These experiments indicate that the nylon nets take about three times as many whitefish as the cotton, but take fish of essentially the same size composition.

INTRODUCTION

The mathematics of gill-net selection is important to the biologist who wishes to examine the size or age composition of fish populations from catches taken with experimental nets, to the authority responsible for legal restrictions on mesh sizes, and to those concerned with the design and testing of fishing gear.

Baranov was probably the first worker to appreciate fully and investigate intensively the problem of gill-net selection (Baranov, 1948; Andreev, 1955; Treschev, 1957). As early as 1913 he established, from experimental nettings of Caspian herring, that $\phi = KL_m$, where ϕ is the bar measure of the mesh, L_m the modal length of the fish caught in it, and K a constant, in this case 0.125. In 1924 he demonstrated that the same relationship applied for the roach in lakes around Moscow, except that for this fish the value of K was 0.150. In addition, Baranov showed that the most direct relation between the size of fish and mesh size is expressed by the equation, $4\phi = kG_m$, where G_m is the girth of the fish caught in modal numbers and 4ϕ the perimeter of the mesh; k is a constant proportional to K[1]. He found that k was the same for both the Caspian herring and the roach, indicating that fish of the same girth of the two species were caught equally well in nets of the same mesh, as far as the effects of their size were concerned. The differences in the ratios based on body length were obviously due to the fact that the herring was more slender than the roach. Baranov found these fish were taken in maximum numbers when the girth of the fish was approximately 25 percent greater than the perimeter of the mesh.

Turning his attention to the captured fish of lengths other than the mode, Baranov assumed as a working hypothesis that the probability of capture of fish of a given size in a given mesh could be described by the normal (Gaussian) curve of probability. He further assumed that, with respect to the fish of the respective modal length that each net took, all

[1]This relation between K and k is only an approximation based on the assumption that the girth of a fish is strictly proportional to its length. That such an assumption is not justified in all cases is shown by the fact that the length-girth relationship for the South Bay whitefish takes the form: $G = 0.685L - 1.45$.

the nets would fish with equal efficiency. Hence, when two meshes A and B were fished simultaneously, he could determine the abundance of the modal length classes L_{mA} and L_{mB} relative to each other from the numbers of each taken in the respective nets. Further, mesh A, for instance, would also take a certain number of fish of length L_{mB} which we can designate as ${}_{C}L_{mB'}$. From the relationship

$$\frac{{}_{C}L_{mB'}}{{}_{C}L_{mB}} \cdot {}_{C}L_{mA}$$

(where C represents the catch) can be derived the relative efficiency of mesh A with respect to the capture of fish of length L_{mB}. Baranov determined the position of the ordinate representing this fractional efficiency from a table of probability ordinates. He then related the position of the ordinate in terms of standard deviation to the difference in length, $L_{mA} - L_{mB}$, and constructed a probability curve for capture in mesh A from the datum so derived and the modal length, L_{mA}. The procedure is described in his extensive treatise on the *Theory and Assessment of Fishing Gear* (Baranov, 1948).

The work of Baranov was extended by a number of students and colleagues, who were primarily interested in investigating the relation $\phi = KL_m$ for different species. Leksutkin, for example, determined the value of K for Volga, Dolgin, and Agrakan herring, Caspian carp and shad, and the bigeyed shad (Andreev, 1955; Treschev, 1957). These workers, however, did not appreciably advance the study of selection of fishes of other than modal lengths. It remained for Holt (1957) to give another demonstration of the deviation of the length-selectivity curves from the catch curves of several simultaneously fished meshes.

Holt's approach was similar to that taken by Baranov inasmuch as he assumed that the selectivity curve would take the form of a normal frequency distribution, and he determined its parameters from the ratio of catches from successive pairs of net sizes. He also assumed that the efficiencies of the two nets would be similar for fish of their respective modal lengths. He added one assumption that Baranov did not make, namely, that the standard deviations of the distributions for two adjacent net sizes would also be equal. Holt also gave more concrete evidence of the normal character of the selectivity curve by citing some experiments by Rollefson (1953) in which relatively unselective trawls were fished on the same grounds as gill nets. When the percentages of the different lengths of fish caught in the gill nets were expressed as fractions of the corresponding percentages in the trawl catches, a normal frequency distribution was obtained. Holt began with the equation

$$C_L = nP_L p_m \cdot e^{-\frac{(L-L_m)^2}{\sigma^2}}$$

where C_L is the number of fish of length L caught, L_m the modal length caught, n the number of operations or duration of the fishing, P_L the number of fish of length L liable to capture, p_m the fishing power of the mesh in question with respect to the fish caught in modal numbers, e is the base of natural logarithms, and σ the standard deviation of the distribution. He then showed that the ratio of the catches for two different meshes fished together could be described by an equation that was linear for L:

$$\log \frac{{}_{B}C_L}{{}_{A}C_L} = \frac{2({}_{B}L_m - {}_{A}L_m)}{\sigma^2} \cdot L + \left\{ \frac{{}_{A}L^2_m - {}_{B}L^2_m}{\sigma^2} + \log \frac{B^{P_m}}{A^{P_m}} \right\}$$

in which ${}_{B}C_L$ represents the catch of length L taken in mesh B and so forth.

From the terms of Holt's second equation it can be seen that, for the catches of any pair of nets slightly differing in mesh size, a plot of $\log \frac{{}_{B}C_L}{{}_{A}C_L}$ against various values of L should give a straight line if the equation holds. The slope *(b)* of the line so found is equal to the term $\frac{2({}_{B}L_m - {}_{A}L_m)}{\sigma^2}$.

The values ${}_{B}L_m$ and ${}_{A}L_m$ must be determined independently. Assuming $\frac{B^{P_m}}{A^{P_m}} = 1$ and hence that its logarithm was zero, Holt was able to write

$$a \text{ (the } y \text{ intercept)} = \frac{{}_{A}L^2_m - {}_{B}L^2_m}{b}$$

and further, assuming that $L_m = K\phi$, ϕ being again the bar measure of the mesh as above, he could write that

$${}_{A}L_m + {}_{B}L_m = K(\phi_A + \phi_B) = -\frac{2a}{b}$$

from which ${}_{A}L_m$ and ${}_{B}L_m$ can be derived. Having obtained these values then σ can be found from either the slope or from the intercept.

Holt applied his analytical procedure to Peterson's (1954) catch records for sockeye salmon from the Fraser river and to Hodgson's (1933) data for North Sea herring, and obtained remarkably consistent results in both instances. Beverton[2], however, has pointed out that the spread of the selection curves increases with the size of the mesh, which weakens one of Holt's assumptions. Holt also pointed out that the selectivity curve was not always normal in form and cited some recent catches of North Sea herring in which the curve seemed skewed or even bimodal. He suggested these anomalies arose because the herring were caught by entangling their maxillæ and opercula as well as by wedging their bodies into the meshes.

Recently Holt's method of determining mesh selection was applied to herring catches from Newfoundland waters (Olsen, 1959). Olsen, however, did not specify the exponential function in advance but left it in a general form. He found a curve, to which he fitted a parabola, between the logarithms of the catches of fish of a given length in the two nets compared and the length of the fish concerned. Olsen's selection curves were therefore slightly skewed, and his treatment presents the general case of which Holt's original equation is a specific instance.

In the present study a third but related approach is made to the problem of net selection. A direct fit is sought to the normal probability curve derived from the relative frequency of capture of fish of a given size class in a series of gill nets with graded mesh fished simultaneously. The method is a graphical one, but with adequate data does not depend greatly on a subjective fit of points by eye. There appears to be satisfactory but not completely perfect fit of the normal curve between the relative efficiency of capture and the size of the fish as expressed by the logarithm of the girth: perimeter ratio. The whitefish was chosen for this study because, with its small mouth and smooth body, it conforms almost ideally to Baranov's wedge theory of fish capture by gill nets. Some comparisons are also made between the selectivities of nylon and cotton gill nets.

[2]Letter from S. J. Holt.

NETTING AND SAMPLING AT SOUTH BAY

The data presented here were obtained from experimental gangs of gill nets comprised of a fixed series of mesh sizes fished in South Bay, Lake Huron, since 1954 by the Research Division of the Ontario Department of Lands and Forests. All nets were hung on the half and the thread sizes, mesh sizes, and depths of the nets are shown in Table 1. In 1954, 1955, and 1956 the length of the individual net was 50 yards, but it was increased to 150 yards in 1957 and 1958. During the first 3 years both cotton and nylon gangs were fished and in a considerable number of settings double gangs, made up of alternating cotton and nylon nets, were fished to permit a simultaneous comparison of the efficiencies of the two materials. In 1957 and 1958 the gangs were of nylon webbing only.

Records were kept of the total number and weight of each species caught in each mesh size. Measurements of fork fish lengths and weights were made on samples in all years and of fish girth in 1958 (Figure 1). From 1954 to early August of 1958, samples of from 5 to 15 fish were taken from all nets which caught more than 5 fish, and all fish were measured when the catches were smaller. When the measured sample represented only a portion of the catch, the total number

TABLE 1.—*Dimensions of the gill nets in the experimental gangs*

Net specifications	Mesh size[1] (inches)									
	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½
Cotton nets										
Thread size..	90	80	80	80	70	80	70	50	50	50
	6	6	6	6	6	6	6	6	6	6
Number of meshes deep	40	40	40	33	30	24	24	24	24	18
Nylon nets										
Thread size	140	140	140	140	140	140	210	210	69	69
	2	2	2	3	3	3	3	3		
Number of meshes deep.	48	40	36	32	30	26	24	24	24	18

[1]Stretched measure from knot to knot.

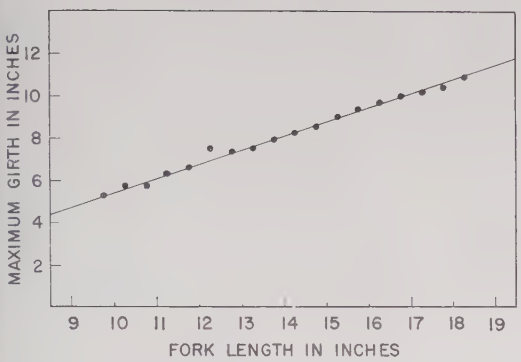

FIGURE 1.—The relationship between the girth and fork length of South Bay whitefish, based on measurements of 536 specimens from the 1958 pound-net catches.

caught was counted and the data were prorated accordingly. During August 1958 all whitefish taken in experimental nets were measured.

SELECTIVITY OF THE NYLON GANGS

The numbers of fish of each length class caught in each mesh size of the nylon nets are shown in Table 2. It is immediately apparent that the data present the typical relation proposed by Baranov. The range of whitefish sizes increases as the mesh size increases and the modal size of fish taken in a given gill net tends to be proportional to the mesh size. The K value in this case is approximately 0.162.

The data in Table 2 were treated as follows: First, girth:perimeter ratios were calculated for each mesh for each size class, using the values for girths given in the right hand column of the table. A plot was then made for each size class, with the number of fish captured being plotted against the logarithm of the girth:perimeter ratio, as is shown in the solid line in Figure 2. The logarithm was used because there was a pronounced positive skew when both variables were plotted on an arithmetic scale. The frequency distribution is essentially symmetrical, however, with the logarithmic transformation. Frequency curves such as the one in Figure 2 were plotted for each size class from 10.25 to 15.75 inches. Sizes outside this range were not considered because the frequency distributions of the smaller and larger size classes were obviously truncated through the lack of a suitably wide range of mesh sizes. In drawing the curves, they were fitted closely to the points and no attempt was made to give them any preconceived symmetry.

TABLE 2.—*Number of whitefish caught in experimental gangs of nylon gill nets during the years 1954 to 1958*

Fork length (inches)	Mesh size (inches)									Girth[1] (inches)
	4½	4	3½	3	2¾	2½	2¼	2	1¾	
7.5-7.9	—	—	—	—	—	—	—	—	16	4.0
8.0-8.4	—	—	—	—	—	—	—	22	38	4.3
8.5-8.9	—	—	—	—	—	—	1	35	20	4.6
9.0-9.4	—	—	—	—	1	—	7	13	5	4.9
9.5-9.9	—	—		—	1	5	7	30	3	5.2
10.0-10.4	—	—	—	—	4	35	42	23	2	5.5
10.5-10.9	—	—	—	4	25	104	72	29	3	5.9
11.0-11.4	—	1	1	16	105	169	116	28	—	6.3
11.5-11.9	—	—	—	28	78	98	26	—	2	6.6
12.0-12.4	—	—	1	59	62	42	12	2	1	6.9
12.5-12.9	—	—	14	86	105	56	11	1	—	7.3
13.0-13.4	—	1	40	111	84	35	10	—	—	7.6
13.5-13.9	—	1	35	70	31	13	2	—	—	7.9
14.0-14.4	—	6	48	36	15	5	2	—	—	8.3
14.5-14.9	—	13	28	15	5	—	—	—	—	8.7
15.0-15.4	4	13	25	12	3	—	—	—	—	9.0
15.5-15.9	6	17	19	2	2	—	1	1	—	9.3
16.0-16.4	14	23	11	—	—	—	—	—	—	9.6
16.5-16.9	28	31	20	5	—	—	—	—	—	10.0
17.0-17.4	51	42	8	5	—	—	—	—	—	10.3
17.5-17.9	32	30	3	1	—	—	—	—	—	10.7
18.0-18.4	15	28	3	—	—	—	—	1	—	11.1
18.5-18.9	26	12	1	—	—	1	—	—	—	11.4
19.0-19.4	13	4	—	—	—	—	—	—	—	11.7
19.5-19.9	7	2	—	—	—	—	—	—	—	12.0
20.0-20.4	3	1	—	—	—	—	—	—	—	12.3
20.5-20.9	0	—	—	—	—	—	—	—	—	12.7
21.0-21.4	1	—	—	—	—	—	—	—	—	13.0
24.0	1	—	—	—	—	—	—	—	—	14.9

[1]Read from graph (Figure 1) at the initial length of each interval and rounded off to first decimal place.

The next step was to bring these curves to the same basis by compensating for the unequal distribution of the various size classes in the population. The area under each of the various curves was measured by counting squares and the plotted ordinates multiplied by the quotient obtained by dividing the area found into a standard area of one unit. The assumption thus was made that all nets had the same relative total efficiency over the respective size ranges which they took. Curves were then drawn through the adjusted ordinates as is illustrated by the dashed line in Figure 2. This process yielded curves which, when superimposed, all appeared to be essentially the same. A master plot, therefore, was made of the adjusted frequencies for all

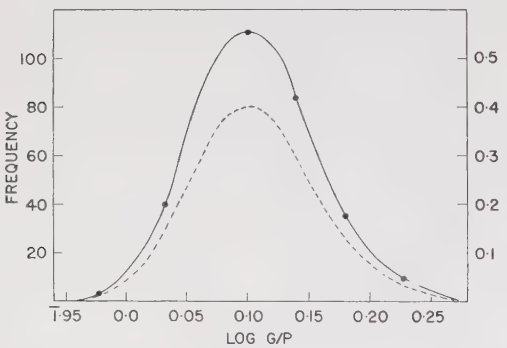

FIGURE 2.—The selectivity curve for South Bay whitefish of the 13.25-inch length class. G is the girth of the fish and P the perimeter of the mesh. The solid line is fitted to the observed frequencies (left hand scale). The dashed line is drawn through the frequencies adjusted on the basis that the area under the curve is unity (right hand scale).

the length classes considered and a single curve fitted to the points (Figure 3).

In making the master plot, the girth: perimeter ratios were grouped into class intervals as indicated and the mean of the adjusted frequencies within each interval was calculated. These means were used as the basis for drawing the freehand curve. The mean and the standard deviation of the combined data were also calculated and were found to be 0.111 and ± 0.0514, respectively, expressed as common logarithms. The mode was found by inspection to be 0.100. The theoretical frequency curve shown in Figure 3 was then drawn by referring the above mode and standard deviation together with the modal frequency (0.40) to a table of ordinates for the normal frequency distribution. It is evident from the figure that the theoretical distri-

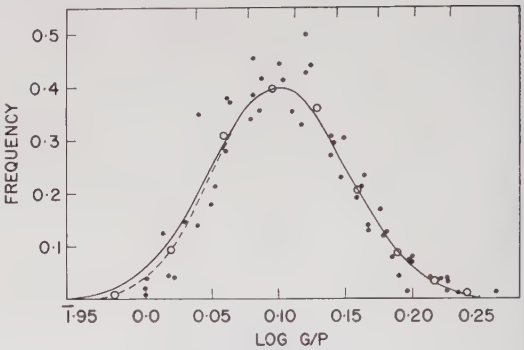

FIGURE 3.—The selectivity curve for South Bay whitefish of all length classes from 10.25 to 15.75 inches. The solid dots represent the observed frequencies adjusted on the basis that the curve encloses unit area. The open dots represent these adjusted frequencies averaged over the class intervals indicated along the top of the figure. These intervals are log 1.00 to log 1.09, log 1.10 to log 1.19 etc.

bution agrees with the observed one, except that even with the logarithmic transformation some skewness still remains, as the discrepancy between the two lines in the figure indicates. Alternatively the theoretical distribution curve could be fitted by the method of moments (Figure 4), as described by Croxton and Cowden (1959). By this method it can be shown that the skew in the distribution plotted is comparatively little ($\alpha_3 = 0.445$) and the leptokurtosis is negligible ($\alpha_4 = 3.05$).

If the skew still remaining is ignored, it is possible to tabulate a good approximation of the relative frequencies with which any mesh would be expected to take any length of South Bay whitefish (Table 3). These frequencies can then be used as indices of the efficiency of the different meshes with respect to whitefish of various lengths. Moreover, an index of the efficiency with which the entire gang fishes each length class can be obtained by

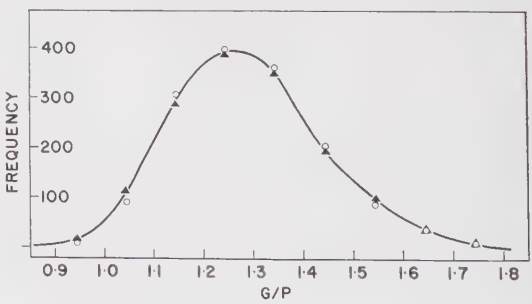

FIGURE 4.—The gill-net selectivity curve for South Bay whitefish fitted by the method of moments. The circles and triangles represent observed and calculated frequencies respectively.

TABLE 3.—*The efficiencies with which nylon gill nets catch South Bay whitefish*

[The data are based on the normal frequency distribution curve in Figure 3.]

Fork length (inches)	Mesh size (inches)										Total
	4½	4	3½	3	2¾	2½	2¼	2	1¾	1½	
5.0-5.4	—	—	—	—	—	—	—	—	—	.001	.001
5.5-5.9	—	—	—	—	—	—	—	—	.000	.016	.016
6.0-6.4	—	—	—	—	—	—	—	.000	.005	.100	.105
6.5-6.9	—	—	—	—	—	—	.000	.002	.036	.270	.308
7.0-7.4	—	—	—	—	—	—	.001	.014	.135	.400	.549
7.5-7.9	—	—	—	—	—	.000	.005	.061	.287	.350	.709
8.0-8.4	—	—	—	—	.000	.002	.026	.165	.392	.218	.804
8.5-8.9	—	—	—	—	.001	.012	.085	.298	.375	.101	.872
9.0-9.4	—	—	—	.000	.006	.043	.189	.390	.268	.036	.931
9.5-9.9	—	—	—	.003	.021	.111	.309	.386	.150	.010	.991
10.0-10.4	—	—	.000	.011	.060	.209	.386	.311	.071	.003	1.050
10.5-10.9	—	—	.001	.043	.156	.345	.378	.173	.020	.000	1.120
11.0-11.4	—	.000	.007	.124	.299	.400	.256	.063	.004	—	1.150
11.5-11.9	—	.001	.019	.209	.369	.369	.170	.029	.001	—	1.170
12.0-12.4	—	.002	.051	.299	.399	.296	.104	.011	.000	—	1.160
12.5-12.9	.000	.009	.109	.386	.359	.183	.041	.003	—	—	1.090
13.0-13.4	.001	.024	.173	.399	.296	.113	.018	.001	—	—	1.020
13.5-13.9	.004	.050	.264	.387	.210	.063	.007	.000	—	—	.963
14.0-14.4	.013	.109	.344	.296	.122	.026	.002	—	—	—	.913
14.5-14.9	.033	.190	.397	.197	.063	.010	.001	—	—	—	.891
15.0-15.4	.060	.255	.393	.134	.035	.004	.000	—	—	—	.881
15.5-15.9	.099	.319	.361	.086	.017	.002	—	—	—	—	.885
16.0-16.4	.150	.369	.309	.052	.009	.001	—	—	—	—	.886
16.5-16.9	.229	.399	.227	.024	.003	.000	—	—	—	—	.883
17.0-17.4	.289	.393	.167	.013	.001	—	—	—	—	—	.864
17.5-17.9	.357	.350	.104	.005	.000	—	—	—	—	—	.819
18.0-18.4	.394	.286	.060	.002	—	—	—	—	—	—	.741
18.5-18.9	.399	.232	.038	.001	—	—	—	—	—	—	.671
19.0-19.4	.392	.187	.027	.001	—	—	—	—	—	—	.607
19.5-19.9	.355	.134	.013	.000	—	—	—	—	—	—	.503
20.0-20.4	.315	.096	.007	—	—	—	—	—	—	—	.419
20.5-20.9	.252	.059	.003	—	—	—	—	—	—	—	.313
21.0-21.4	.204	.039	.002	—	—	—	—	—	—	—	.245
21.5-21.9	.160	.025	.001	—	—	—	—	—	—	—	.186
22.0-22.4	.122	.016	.000	—	—	—	—	—	—	—	.139
22.5-22.9	.090	.010	—	—	—	—	—	—	—	—	.100
23.0-23.4	.065	.006									.071
23.5-23.9	.045	.003	—	—	—	—	—	—	—	—	.049
24.0-24.4	.031	.002	—	—	—	—	—	—	—	—	.033
24.5-24.9	.021	.001	—	—	—	—	—	—	—	—	.022
25.0-25.4	.014	.001	—	—	—	—	—	—	—	—	.015

summing the frequency data for the class (last column, Table 3). The varying efficiency of the gang for capturing the various size classes can then be compensated for by using these indices to divide the observed numbers of fish taken and so provide an estimate of the relative numbers of each size group in the population from which the catch was drawn. An example of such a correction applied to the 1958 catches of whitefish in South Bay is shown in Figure 5.

It should be noted, however, that if all the nets fished are of a single mesh, use of weighing indices based on the normal curve will give a serious underestimate of the population of the fish of smallest size taken in the net. For example, the ordinate in Figure 3 at the log girth:perimeter ratio 0.0 (ratio 1.0) is 0.060 if read from the normal curve, but if read from the empirical curve in the figure it is 0.040. The use of the index toward the extreme limit of the small fish taken in a single net could lead, therefore, to an underestimate of 30 percent or greater. Such discrepancies are minimized in summing the catch results

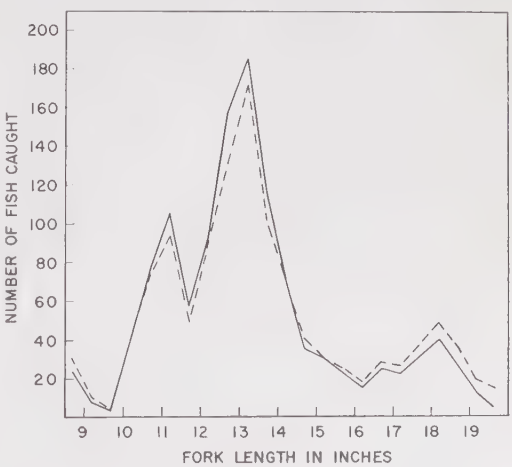

FIGURE 5.—The size composition of the 1958 catch of South Bay whitefish. The observed and theoretical compositions are represented by the solid and dashed lines respectively.

of a graded series of nets where the effect of the underestimate so made is only on a small fraction of the total catch. In Figure 5 the population estimates have been carried down only to the 8.75-inch class, a size still well represented in the smallest mesh.

COMPARATIVE EFFICIENCIES OF NYLON AND COTTON WEB

When nylon gill nets were introduced, it was expected that their capacity to catch fish might differ from that of cotton, linen, or hemp nets because there were differences in the thickness, elasticity, and visibility of the threads. Reports soon came in that the catches from the nylon nets were much greater than those from nets of other materials, and in some cases appeared also to be of a different size composition. Consequently a controversy arose concerning the possible effects of nylon gill nets on fish stocks and the need for special regulations on such gear (Van Oosten[3]). A number of investigators, therefore, have undertaken to compare the efficiency of the different netting materials by experimental and statistical procedures.

Mesh sizes from 1¾ to 7 inches, stretched measure, have been considered in the various investigations and in general the nylon gill nets were found to capture more fish per unit effort than the nets of other materials. The differences in efficiencies, however, varied with the materials compared (Lawler, 1950; Molin, 1951; Hewson, 1951, 1952; Atton, 1955; Ridenhour and DiConstanzo, 1956; Saetersdal, 1957) and with the species taken (Saetersdal, 1957; Scidmore and Scheftel, 1958). There is also some evidence that nylon nets are more effective in clear waters, where the lesser visibility of thread would be an advantage (Brandt and Liepolt, 1955). On the other hand, cotton nets sometimes captured more fish than nylon during dark phases of the moon, when the lesser visibility of the latter material would be of no special advantage.

The reports on the size compositions of catches from nylon, linen, and cotton nets are contradictory. Molin (1952) concluded that the nylon nets took more of the larger fish than the cotton nets did. Hewson (1951), Ridenhour and DiConstanzo (1956), and Scidmore and Scheftel (1958), on the contrary, reported that nylon nets took the same size fish as cotton and linen nets.

During the years 1954 through 1956 some of the South Bay experiments were carried out with a double length gang of gill nets in which nylon and cotton sections of corresponding mesh were linked end to end (Table 1). The aim of these particular experiments was to approximate as closely as possible the condition in which equal areas of cotton and nylon web sampled the same population for the same length of time.

Tables 4 and 5 show the number of whitefish of each length class caught by each nylon and cotton net respectively. Since the areas of these nets were approximately equal and the fishing periods the same, the data in these tables can be used directly as catch-per-unit-effort statistics. It is immediately evident that the total catch of the nylon nets was almost three times as great as that of the cotten nets. There was apparently no significant difference, however, between the proportions of the different length classes caught by the nylon and the cotton gangs. A 2 by 2 contingency test of the data in the extreme right hand columns of Tables 4 and 5, in which the fish were grouped into classes 13 inches and below and 14 inches and above, yielded a χ^2 of 0.071, indicating that such differences in proportion as do appear in the data could be expected to occur by chance alone.

Because the number of fish in the paired comparisons above was small, a further test was made which incorporated the catches made with cotton nets before the introduction of nylon, and those taken with nylon gear after the cotton nets were abandoned. In this test a plot was made of the average sizes of mesh required to take successive length classes of fish (Figure 6). It is evident that the data for the cotton and the nylon lie on the same regression line; hence, the two materials must have drawn comparable samples of fish.

CONCLUSIONS

The curve for the selectivity of gill nets obtained from the catches of South Bay whitefish is definitely skewed and requires a logarithmic transformation of the abscissae before it approximates the form of a normal frequency distribution. According to this curve, a gill net will take very few whitefish

[3]Van Oosten, J. (1949) Condensed transcript of proceedings of the conference on nylon fish netting held at Erie, Pennsylvania. 30 pp. (Mimeo.)

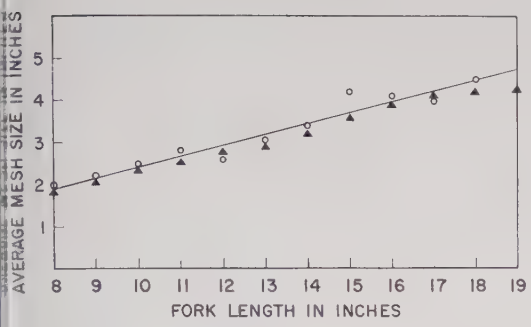

FIGURE 6.—The average mesh sizes required to capture successive length classes of South Bay whitefish. The circles represent data for cotton nets and the triangles represent those for nylon nets.

as long as the perimeter of the mesh is greater than the girth of the fish. As the girth: perimeter ratio exceeds unity, the efficiency of the net increases rapidly until it reaches a maximum value at a ratio of 1.26 (log value 0.10). This girth:perimeter ratio for maximal efficiency agrees well with the values found by Baranov, Koltanovsky, and Leksutkin for the roach, barbel, and other species (Andreev, 1955). It is quite different, however, from the ratio of 1.08 which Holt (1957) calculated from the catches of the Fraser River sockeye. With a still further increase in the girth: perimeter ratio the efficiency with which the South Bay whitefish are captured by gill nets declines until it is again negligible at a ratio of 1.77 (log value 0.25). The sharpness of the selection of whitefish by a particular gill net is of the same order as that found for other species by Baranov (1948) and Olsen (1959)—that is, all size classes which are taken with an efficiency of 50 percent of the peak efficiency or greater lie within a range which is of the order of ±15 percent of the modal length.

On the basis of the efficiency curve described here, the catch data for South Bay whitefish taken in gill nets can be adjusted for net selectivity to give the estimated size compositions of the populations from which they were drawn. Similar estimates can be made for catches taken by gangs of nets, all of a single mesh size, but caution should be observed in estimating the relative numbers of the smaller size classes captured because there is slight asymmetry still remaining in the observed selection curve. It is probable that the selection curve determined for the South Bay whitefish will also be applicable to other populations of that species if consideration is given to local differences in the girth: body length relation.

Little or no difference in size selection is to be found between nylon and cotton gill nets although the nylon takes the whitefish more efficiently over the whole vulnerable size range.

ACKNOWLEDGMENTS

We are grateful to Messrs. R. J. H. Beverton and S. J. Holt for their comments and reference pertinent to net selectivity and to the Ministry of

TABLE 4.—*Number of whitefish caught in cotton gill nets fished in combined cotton-nylon gangs*

Fork length (inches)	Mesh size (inches)										Total number
	1½	1	3½	3	2¾	2½	2¼	2	1¾	1½	
7.0-7.4								2			2
7.5-7.9								1			1
8.0-8.4							1				1
8.5-8.9											
9.0-9.4							2				2
9.5-9.9								1			1
10.0-10.4					1	3					4
10.5-10.9	—			1		1					1
11.0-11.4					1						1
11.5-11.9				3	2						5
12.0-12.4		1		2							3
12.5-12.9			2	1	1						4
13.0-13.4		1	2								3
13.5-13.9											
14.0-14.4			1	2							3
14.5-14.9		1									1
15.0-15.4	1										1
15.5-15.9	1	2	1								4
16.0-16.4											
16.5-16.9	2		1								3
17.0-17.4	1										1
17.5-17.9											
Total											39

TABLE 5.—*Numbers of whitefish taken in nylon gill nets fished in combined cotton-nylon gangs*

Fork length (inches)	Mesh size (inches)										Tota number
	4½	4	3½	3	2¾	2½	2¼	2	1¾	1½	
7.0-7.4	—	—	—	—	—	—	—	—	—	—	—
7.5-7.9	—	—	—	—	—	—	—	—	—	—	—
8.0-8.4	—	—	—	—	—	—	—	2	3	—	5
8.5-8.9	—	—	—	—	—	—	—	3	—	—	3
9.0-9.4	—	—	—	—	—	—	1	—	—	—	1
9.5-9.9	—	—	—	—	—	—	—	—	—	—	—
10.0-10.4	—	—	—	—	—	—	1	—	—	—	1
10.5-10.9	—	—	—	1	2	—	1	1	1	—	6
11.0-11.4	—	—	—	—	5	5	—	—	—	—	10
11.5-11.9	—	—	—	2	2	1	—	—	—	—	5
12.0-12.4	—	—	—	3	—	—	—	—	—	—	3
12.5-12.9	—	—	1	1	2	1	—	—	—	—	5
13.0-13.4	—	—	1	4	1	—	—	—	—	—	6
13.5-13.9	2	—	5	3	4	—	—	—	—	—	14
14.0-14.4	2	4	4	1	1	1	—	—	—	—	13
14.5-14.9	—	2	1	—	—	—	—	—	—	—	3
15.0-15.4	3	1	1	—	—	—	—	—	—	—	5
15.5-15.9	—	1	2	—	—	—	—	—	—	—	3
16.0-16.4	1	2	—	1	—	1	—	—	—	—	5
16.5-16.9	1	4	2	1	—	—	—	—	—	—	8
17.0-17.4	3	2	1	1	—	—	—	—	—	—	7
17.5-17.9	3	1	—	—	—	—	—	—	—	—	4
18.0-18.4	1	1	—	—	—	—	—	—	—	—	2
18.5-18.9	1	1	—	—	—	—	—	—	—	—	2
19.0-19.4	—	—	—	—	—	—	—	—	—	—	—
19.5-19.9	—	—	—	—	—	—	—	—	—	—	—
20.0-20.4	—	—	—	—	—	—	—	—	—	—	—
20.5-20.9	2	—	—	—	—	—	—	—	—	—	2
Total											113

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Development of a Program to Sample Young Fish in a Lake[1]

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ABSTRACT

Need for a more efficient program to sample young-of-the-year game and pan fish in Clear Lake, Iowa, led to an intensive survey conducted during the summers of 1956 and 1957. A seining schedule was followed in which weeks, times of day, and stations were randomized following the procedures for the Latin square design. On the basis of information gained from the 1956-1957 survey, a more efficient plan was outlined for integration into the Clear Lake fishery research program. Seining is to be limited to the night because catches of most species were higher then and the mean lengths of young fish are the same as those taken during daylight. Sampling will be according to a Latin square schedule during the 6 weeks prior to August 31. Sampling in the preceding week will permit practice and elimination of any procedural problems. Growth of young-of-the-year fishes differed in various parts of the lake necessitating sampling at several stations.

INTRODUCTION

Adequate sampling of fish populations is one of the more difficult aspects of fisheries research. The present study outlines the procedures used to develop a sampling program for specific purposes. While direct application of the methods used may not be suitable elsewhere, the basic steps are similar to those which might be used to develop many other programs. First, the overall project must be outlined to determine what population is to be studied and what knowledge is to be sought concerning the population. Additional questions concerning the sample itself that must be answered are: (1) the size of sample required; (2) the resources in terms of time, money, equipment, and personnel that are available; and (3) what foreknowledge concerning the population is available which might aid the research worker to increase the efficiency of the sampling design. After the above questions have been reviewed, the designing of the survey may proceed.

In the present study the population was the young-of-the-year game and pan fishes of Clear Lake, Iowa. Clear Lake (Figure 1), located in north-central Iowa, is a large (3,600 acres), shallow (20 feet maximum depth), eutrophic lake (Bailey and Harrison, 1945; Pearcy, 1953). Biologists of the Iowa Cooperative Fisheries Research Unit have seined young-of-the-year fish at Clear Lake, Iowa, each summer since 1946 and some collections were made in 1942 and 1943. The writer collected data from 1954 through 1957 and initiated an intensive study in 1956. The following species of fish were taken in sufficient numbers for study: black bullhead, *Ictalurus melas;* white bass, *Roccus chrysops;* yellow bass, *Roccus mississippiensis;* largemouth bass, *Micropterus salmoides;* pumpkinseed, *Lepomis gibbosus;* bluegill, *Lepomis macrochirus;* black crappie, *Pomoxis nigromaculatus;* walleye, *Stizostedion vitreum vitreum;* and yellow perch, *Perca flavescens.*

Evaluation of year-class success and growth was the primary objective of this study. Data on food habits and ecological distribution were also sought and were considered when the sampling scheme was developed. Actual population estimates of age-group O fish were not considered to be feasible. Some index must suffice to indicate the relative sizes of the various year classes. For most comparative purposes the catch per unit of effort, catch per bag-seine haul in this case, is the most convenient measure of abundance. Such a procedure requires standardization of the entire sampling technique. Seining was considered the most appropriate method of obtaining a sample of fish since the fish were largely limited to the littoral zone.

Prior to 1956, seining with a "common sense" seine or a 30-foot bag seine (½-inch

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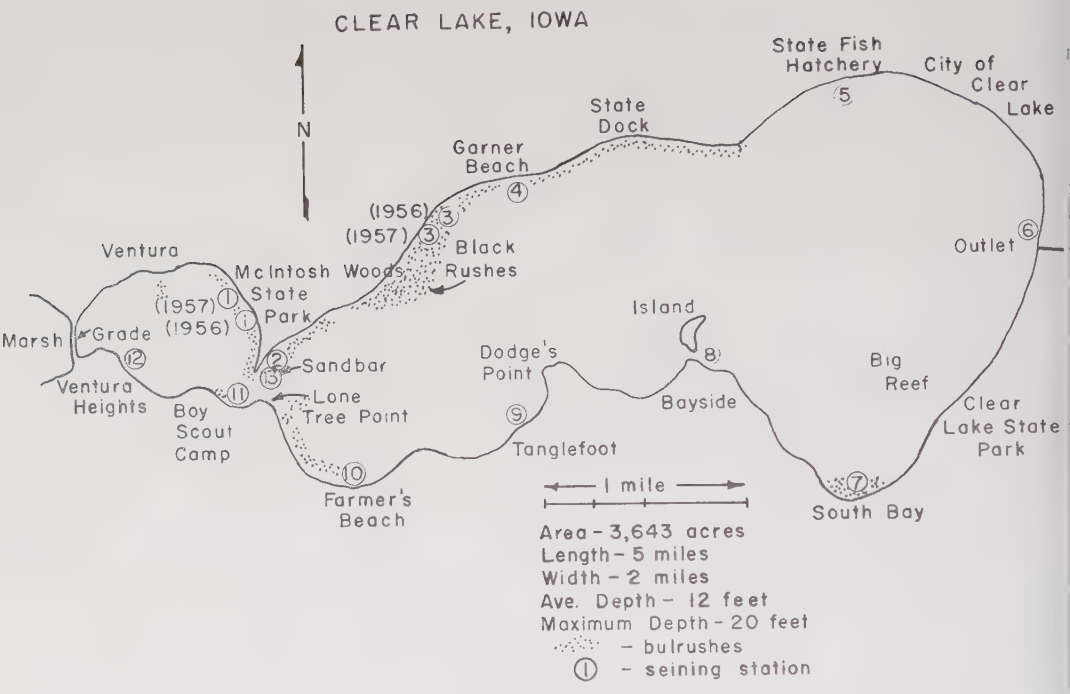

FIGURE 1.—Map of Clear Lake, Iowa, showing 1956-57 seining stations.

mesh wings and ¼-inch mesh bag) was usually done once each week. If they were obtainable with a reasonable amount of effort, 50 fish of each species were measured and the excess was counted. The number of seine hauls and stations sampled depended upon the numbers of the different species which could be obtained. No set pattern of seining was followed and, if all species could be collected at the first location, seining was terminated for that week.

DESIGN OF THE 1956-1957 SURVEYS

In 1956 and 1957 sampling was systemized to provide more exact information on factors which may affect the sampling. The seining program at Clear Lake was only part of the research program at the lake, and therefore the time available for this activity was limited to 2 days each week. One seine haul per hour was as much as could be accomplished by the two biologists when time for measuring and counting the fish and for travel between stations was allowed. On the basis of one haul per hour, 24 hauls could be made during one complete day which would allow a maximum of 24 seining stations. To reduce the travel time and also to obtain an estimate of the variation between hauls within a station at a given time, two seine hauls were made at each of 12 stations. Analysis of the data by statistical methods required randomization. Since 12 stations and twelve 2-hour periods were to be used, the randomization procedures for the Latin square design seemed appropriate (Snedecor, 1956, pp. 304-310). This design was used even though sampling stations could not be picked at random because many locations were not seinable.

Stations 1 through 12 (Figure 1) were used in the basic sampling schedule for 1956 and 1957. A station was sampled every 2 hours during the weekly 24-hour sampling period so that each week two seine hauls were taken in a 2-hour period at each of the 12 stations. The schedule also provided that no station would be sampled twice at the same time of the day within a 12-week period, and each 2-hour period would be sampled once each week. During the study it was determined that a better measure of the difference between catches made at night and during the day was needed. Station 13, therefore, was sampled at noon and midnight once each week during the 1957 season.

A modified 30-foot bag seine was used for all seining of young-of-the-year fishes during

the summers of 1956 and 1957. This seine was composed of ½-mesh in the wings, ¼-inch mesh in the bag, and a cheese cloth patch (about 3 feet square) in the center of the bag. Each haul covered a distance of approximately 75 feet and was made parallel to the shore. One end of the seine was usually kept within a few feet of the shore. The hauls were spaced so that fish captured in the first haul probably would not be recaptured in the second.

Counts of each species captured were recorded for each seine haul. At each regular station 30 fish of each species were measured, if that many were available. All measurements were recorded as total length in millimeters.

ANALYSIS OF THE 1956-57 SURVEY DATA

Since the data were collected following a Latin square schedule, analysis of the year-class success could follow the analysis of variance procedures for this type of design (Snedecor, 1956, pp. 304-307 or Cochran and Cox, 1950, pp. 103-112). An assumption implicit for the analysis of variance is that the errors be normally distributed. The above assumption was not fulfilled by the catch per haul data for young-of-the-year fishes since many of the observations were zero. For example, 68 percent of the hauls in 1957 contained no yellow bass. Therefore, a transformation of the data was made as follows (Kempthorne, 1952):

$$y_{ijk} = \sqrt{x_{ijk} + 0.5}$$

where y_{ijk} = the transformed value of x_{ijk} and x_{ijk} = the catch of young-of-the-year fish of a given species in the ith haul of the jth time period for the kth week.

The procedures have been applied to the 1957 young-of-the-year yellow bass catch data to illustrate the steps involved (Table 1). Using the F test the variation among weeks was significant ($F = 2.39$, where $F_{.05} = 1.88$ with 11 and 110 degrees of freedom) and the variation among times of day and among stations was highly significant ($F = 3.62$ and 2.55, respectively, where $F_{.01} = 2.42$ with 11 and 110 degrees of freedom). These results are to be expected since the survey scheme used in 1956 and 1957 was designed to measure the greatest amount of variation from these sources. Since stations were picked to represent each of the major habitat types and a complete sample of the times of day and weeks was used during the sampling period, all possible variations related to these factors have been obtained.

TABLE 1.—*Analysis of the transformed catch data for young-of-the-year yellow bass, Clear Lake, Iowa, 1957*

Source of variation	df	SS	MS
Weeks	11	187.228	17.021
Time	11	283.609	25.783
Stations	11	199.707	18.155
Error	110	783.766	7.125
Between hauls/same station at same time	144	141.728	0.984
Total	287	1596.038	

Weeks: $F = 17.021/7.125 = 2.389^*$
Time: $F = 25.783/7.125 = 3.619^{**}$
Stations: $F = 18.155/7.125 = 2.548^{**}$
$F_{.05} = 1.88$ with 11 and 110 degrees of freedom.
$F_{.01} = 2.42$ with 11 and 110 degrees of freedom.

$\bar{y} = 518.062/288 = 1.799$

$s_{\bar{y}} = \sqrt{7.125/288} = 0.1573$

$t_{(.05,\ 110)} = 1.981$

C.I. $= 1.799 \pm (0.1573)(1.981) = 1.799 \pm 0.312$

*Significant at the 5 percent level.
**Significant at the 1 percent level.

The mean square for error in Table 1 is an estimate of the variation of the transformed catch per haul data after the variation due to weeks, times of day, stations, and hauls within stations made at the same time have been removed. This error term can be used to compute a confidence interval for the mean of the transformed catch data as follows (Snedecor, 1956, p. 76):

$$\text{C.I.} = \bar{y} \pm s_{\bar{y}}t$$

where $\bar{y}$ = the general mean of the transformed data, $s_{\bar{y}}$ = the standard error of the mean of the transformed data which equals the square root of the error mean square in the analysis of variance table divided by the total number of observations, and t = Student's t obtained from a table (Snedecor, 1956, p. 46) for the desired level of precision and the appropriate degree of freedom for the error term in the analysis of variance table.

The results of these computations for the 1957 young-of-the-year yellow bass catch yield a 95 percent confidence interval of 1.49 to 2.11 for the mean of 1.80.

Differences between the mean catches per haul for any 2 years may be evaluated by making a pooled analysis of the data collected during the 2 years (Paterson, 1939, p. 20; Wishart, 1940, p. 20). An F test of the difference between years can then be made by

dividing the between years mean square estimate by the pooled error within years mean square estimate. If, by use of the F test, the difference between any 2 years is significant at the 5 percent level, the interpretation would be that the difference in year-class success between the 2 years was real unless a 1-in-20 chance sampling had occurred.

The relationship between the transformed data and the population is not proportional, and therefore direct interpretation of the mean of the transformed data into terms of the population or year-class success is not possible. A retransformation, which involves some approximations, could be made but is unnecessary for interpretation. The actual mean catch per haul for the original data would be the best estimate to use to determine the magnitude of the difference in year-class success between years, but the transformed data give a better estimate of the confidence intervals and of tests of significance.

The sampling scheme involving 12 stations was too extensive for future use. A design which would not greatly reduce the precision of the estimates of year-class success but which would require less effort was needed. In order to explore means of reducing effort without loss of precision, the young-of-the-year yellow bass catch data were restricted to the 6 weeks prior to August 31 and to the six 2-hour periods between 6:00 p.m. and 6:00 a.m. when the fish were more available and/or more susceptible to capture in the seine. The number of yellow bass caught per haul during the restricted sampling period was 17.1 instead of 8.3. The number of zero observations was also reduced from 68 percent to 28 percent of the hauls. Since each station could not be equally represented in each week and in each time period, these latter data could not be analyzed following the Latin square model. Even though the variation among stations was necessarily included in the estimated error mean square of the analysis of variance, approximately the same precision was obtained from the restricted data. In addition, it should be noted that these results were obtained with 72/288 of the original effort.

The data collected in 1956 and 1957 contained sufficient information for estimates of precision and sample size requirements in relation to the mean length of the young-of-the-year fishes in Clear Lake. Since the lengths of any given species probably would have the greatest variation at the end of the seining season, only data collected during the last week of August were analyzed for the above information (Table 2). Estimates of sample size needed to detect a predetermined difference from the mean were computed as follows[3] (Cochran, 1953, Chapter 4, or Snedecor, 1956, p. 60): $n' = s^2t^2/d^2$

[3]Other methods could have been used but this formula is probably adequate if the 50 percent chance that the estimated sample size is larger or smaller than required is realized.

TABLE 2.—*Confidence interval and sample size estimates for some young-of-the-year fishes from Clear Lake, Iowa*

[A: August 26—September 1, 1956; B: August 25-31, 1957]

Species	Period	Number measured	Mean length	Estimated variance	C.I.[1]	n'[2]
Yellow perch	A	93	70.7	52.1	69.2-72.2	50
	B	92	72.9	27.1	71.8-74.0	25
Walleye	A	6	89.3	138.3	77.0-101.6	80
	B	0	—	—	—	—
Largemouth bass	A	89	61.6	140.2	59.1-64.1	160
	B	132	60.9	70.1	59.5-62.3	85
Bluegill and pumpkinseed	A	312	30.7	31.6	30.1-31.3	150
	B	247	27.9	49.5	27.0-28.8	270
Black crappie	A	138	52.6	17.0	51.9-53.3	30
	B	26	58.4	37.8	55.9-60.9	50
Yellow bass	A	251	63.6	18.8	63.1-64.1	25
	B	171	65.5	33.8	64.6-66.4	40
Black bullhead	A	99	51.9	66.0	50.3-53.5	110
	B	174	54.4	85.2	53.0-55.8	125
White bass	A	25	89.7	20.8	87.8-91.6	15
	B	17	90.1	13.1	88.2-92.0	10

[1]95 percent confidence interval estimated for the sample mean.
[2]Number of fish needed to estimate the mean length within 3 percent of the true mean with 95 percent confidence.

TABLE 3.—*Differences in millimeters between mean lengths of some young-of-the-year fishes captured from 6:00 a.m. to 6:00 p.m. (D)[1] and from 6:00 p.m. to 6:00 a.m. (N)[1], Clear Lake, Iowa*

[1956 (top line) and 1957 (bottom line) in each weekly period.]

Period	Yellow perch	Largemouth bass	Bluegill and pumpkinseed	Black crappie	Yellow bass	Black bullhead
June 23-29	0.11(N)	5.92(D)	—	—	—	—
	0.74(D)	—	—	—	—	—
June 30-July 6	0.23(N)	5.41(D)	—	—	—	—
	2.63(D)	—	—	—	—	—
July 7-13	2.08(D)	13.58(D)	2.07(N)	—	—	1.48(D)
	0.22(N)	—	7.50(D)	—	—	—
July 14-20	8.05(D)	0.04(D)	2.25(D)	—	2.37(D)	2.38(N)
	0.95(N)	4.39(D)	2.55(N)	0.71(N)	2.34(D)	2.36(N)
July 21-27	4.82(D)	4.84(N)	1.84(D)	0.20(D)	0.53(D)	0.25(N)
	—	1.72(N)	1.00(N)	1.67(D)	3.25(D)	1.68(N)
July 28-August 3	4.30(N)	6.95(N)	0.19(D)	0.66(D)	1.43(D)	2.75(N)
	6.14(D)	4.06(D)	0.15(N)	3.05(D)	2.37(D)	8.80(N)
August 4-10	4.95(D)	5.62(D)	4.43(D)	0.12(N)	0.16(N)	0.39(D)
	2.06(D)	7.98(D)	2.07(N)	—	0.32(N)	1.37(D)
August 11-17	1.14(D)	6.66(D)	0.65(N)	0.27(D)	7.25(N)	—
	0.36(N)	2.69(N)	2.99(N)	6.87(D)	0.97(D)	5.26(D)
August 18-24	4.11(N)	3.05(N)	0.50(D)	2.09(N)	3.32(N)	13.81(N)
	1.02(D)	7.42(N)	0.33(D)	—	—	9.29(N)
August 25-31	2.20(N)	7.15(D)	0.21(D)	1.45(D)	3.11(N)	13.43(D)
	2.23(N)	7.70(D)	0.32(D)	1.48(N)	4.81(D)	9.86(D)
September 1-7	—	—	—	—	—	—
	3.56(N)	1.60(D)	0.55(N)	2.33(N)	1.61(N)	0.51(D)

[1](D) and (N) are used to indicate whether the day or night mean length was the larger.

where $n' =$ the estimated sample size needed to detect a desired magnitude of difference from the sample mean, $s^2 =$ the variance of the sample, $t =$ Student's t obtained from a table (Snedecor, 1956, p. 46) for $n' - 1$ degree of freedom and the desired level of confidence, and $d =$ the difference from the mean which is to be detected.

From Table 2 it can be seen that, for most species of fish, a large enough sample was measured to detect a 3 percent difference from the mean length with 95 percent confidence. Probably the precision of the estimated mean length for black bullheads in 1956 and bluegills and pumpkinseeds in 1957 could have been increased to the desired level if more of the fish which were captured had been measured.

SOURCES OF BIAS AND OF VARIATION

Factors which introduce bias and those which produce variation have two very different effects. Sources of bias are those factors which cause resulting estimates to be consistently high or low while sources of variation affect the precision of estimates. As long as biases are consistent from year to year, they should not cause incorrect interpretations of year-class success. Consideration of the possible sources of bias and variation evident from observation and analysis of the data collected should allow future surveys to be designed more efficiently.

Large variations were expected in the size of the catches and catch composition in relation to the week and the time of day being sampled. As long as the same time periods are used each year, the data should remain comparable for year-class success determinations. Since fish grow each week, the more weeks which are sampled, the more precise resulting growth estimates should be. The differences, however, between the mean lengths of fish caught at two different times of day may or may not be expected to be the same. A comparison of the mean length estimates for each week for young-of-the-year fishes of some species from Clear Lake was made between fish captured from 6:00 a.m. to 6:00 p.m. and those captured from 6:00 p.m. to 6:00 a.m. (Table 3). The inconsistency of the differences indicates that there was probably little or no real difference between the mean lengths of young-of-the-year fish captured during the day and those captured at night.

The major factor affecting the variability due to stations was the difference between the habitats sampled. Differences in species abundance and growth rates were expected between habitats on the basis of earlier observations. The validity of this latter assumption is illustrated in the yellow perch data collected in 1956 (Table 4). Other species show the same phenomenon. An attempt was made, therefore, to sample all habitats, but the effort was complicated by the subjectivity of defining habitats. Resulting estimates of mean

length of a particular species should be weighted according to the numbers of fish caught at each station to obtain the best possible estimates. If the habitats were not sampled in proportion to their occurrence, a further weighting on the basis of the proportion of each habitat type sampled might be required.

TABLE 4.—*Numbers (top line) and mean total lengths in millimeters (bottom line) of young-of-the-year yellow perch collected at selected stations at Clear Lake, Iowa, during successive periods in 1956*

Period	Stations					
	2	4	8	10	11	12
June 24-30	15	9	0	1	2	16
	39	40	—	38	40	37
July 1-7	6	2	0	3	3	44
	44	47	—	42	41	42
July 8-14	8	2	1	0	1	138
	46	50	51	—	50	45
July 15-21	5	0	4	2	4	88
	49	—	50	56	54	48
July 22-28	5	4	26	0	1	54
	60	59	57	—	61	52
July 29-August 4	24	4	9	0	3	56
	62	66	66	—	63	58
August 5-11	11	1	4	1	4	86
	67	66	66	72	66	61
August 12-18	14	9	9	3	2	51
	71	70	63	73	70	62
August 19-25	3	0	19	1	6	16
	76	—	65	76	73	63
August 26-September 1	19	3	26	4	5	39
	76	72	67	76	77	67

Two additional factors which would increase the variability of the data that were not considered when this study was initiated were the homogeneity within stations and the adaptability of the stations to changing water levels. If a station is not homogeneous, the habitat being sampled cannot be accurately defined and weighting procedures become more complicated. Lack of homogeneity also would make an analysis of habitat requirements more difficult. During the 1957 season low water levels required relocation of Stations 1 and 3. Relocation of stations increases the variable factors which must be considered in the year-class success interpretations.

Changes in the habits of the fishes within and between years may affect both year-class success and growth-rate estimates. Increased population size tends to cause individuals to use habitat which is not normally occupied by that species. If expansion of habitat occupation is within seinable waters and if seining stations properly sample the different types of habitat, estimates should not be biased. If, on the other hand, movement is into waters which are not, or cannot, be sampled properly, resulting estimates of year-class strength will be lowered. Changed habits of specific size groups of young-of-the-year fishes would influence growth estimates. If changed habits or increased agility make larger fish less susceptible to capture by seining, estimates of growth and abundance will be low. For the present it must be assumed that young-of-the year fish of a given particular species are equally vulnerable to seining throughout the sampling period and in different years.

Changes in the habits of fishes in relation to day and night should be considered before sampling is limited to either of these periods of time. As long as any changes are consistent between years, comparisons of year-class success should remain valid. There was no evidence collected in 1956 or 1957 to support the possibility that habits changed between night and day as the fish grew larger except in the case of yellow perch. At Station 13 catches of yellow perch were larger at noon early in the season but the larger catches were made at midnight late in the season (Table 5).

Wind direction and strength, and water temperature were recorded whenever a station was sampled, but there were no obvious correlations between these factors and catches of young-of-the-year fishes in Clear Lake. Habitat difference, one of the most important variables, is a result, in part, of wind action and water temperatures. Since temperatures in shallow water are closely related to the time of day, the effects of these factors were so confounded that they were not measured in this study. If stations are properly picked and sampled, it is probable that any meteorological effects might cause some additional variation but no bias.

A PROPOSED YOUNG-OF-THE-YEAR SURVEY SCHEDULE

Since estimates of year-class success and of growth of young fishes are to be made each summer for Clear Lake, the effort that was expended during the 1956 and 1957 studies must be reduced without great loss of precision in the estimates. There are two ways by which the precision of estimates may be increased. First, the size of the sample may be increased and second, the variability of the sample may be reduced. To increase sample size without increasing effort, the efficiency

of the effort must be increased. By limiting the effort to times of the season, times of the day, and stations when and where more fish are available to seining, more fish can be captured per seine haul. At Clear Lake catches were largest from about mid-July through August. Most species of fish were more susceptible to seining during the night and some species could hardly be sampled in the daytime (Table 5).

Since stations cannot be selected randomly, picking stations is subjective and requires the use of stations at which not only large numbers of fish can be captured, but large numbers of as many species as possible can be collected. As long as the same stations are sampled at the same times of the year and of the day in the same manner with the same gear each year, the resulting data should remain comparable. Differences in habits of fishes between years would not be expected to vary to any great extent. Caution should be taken to pick stations which will not be appreciably affected by such factors as water level or shoreline development which cause changes in the habitat. This latter factor could cause some difficulties since future changes at a lake cannot be readily predicted. If the selected stations do not represent the various habitats in the lake equally from year to year, a further source of variation or bias may exist.

On the basis of the foregoing considerations the following sampling program has been proposed for Clear Lake. Samples from which growth estimates can be derived should be collected once each week during the 7-week period from July 15 to August 31. Six stations representing typical habitats should be selected. The order of sampling the stations should be randomized for the first week but during the last 6 weeks should follow a Latin square schedule. Year-class-success studies should include the 6-week period preceding August 31. Seining should be limited to the hours from 6:00 p.m. to 6:00 a.m. with six 2-hour sampling periods being established within that time interval. Two hauls with the bag seine (with the cheese cloth patch in the bag) should be made at each station each time it is sampled. Counts of all fish captured should be made for each seine haul and 30 fish of each species should be measured each time a station is sampled. This sampling scheme is somewhat arbitrary. The time interval of July 15 to August 31 was proposed for the growth studies since growth seems to be most nearly constant during this period. Since all species should be available for seining by July 15 no effort will be wasted on unproductive hauls. August 31 is selected as the end of the sampling period because growth slows down in September.

A 7-week schedule for growth studies and a 6-week schedule for year-class-success studies was proposed for four reasons. First, estimates of growth rate improve as the length of the observation period is extended. Second, the week prior to the start of the 6-week schedule allows new workers to acquaint themselves with the stations, gear, and techniques to be used without endangering the comparability of year-class-success information. Third, if any alteration of gear, stations, or techniques is necessary, these changes can be

TABLE 5.—*Numbers of young-of-the-year fishes in bag-seine catches at Station 13 from Clear Lake, Iowa, at noon (N) and midnight (M), 1957*

Species	Time of day	Period										
		June 23-29	June 30-July 6	July 7-13	July 14-20	July 21-27	July 28-Aug. 3	August 4-10	August 11-17	August 18-24	August 25-31	September 1-7
Yellow perch	N	5	11	28	18	13	7	10	1	2	—	
	M	3	7	16	33	30	56	14	89	5	21	3
Largemouth bass	N	—	—	1	2	15	38	58	30	20	46	21
	M	—	—	—	1	15	57	59	93	38	27	16
Black crappie	N	—	—	—	1	-	-	—	—	—		
	M	—	—	3	18	33	30	2	48	41	51	32
Bluegill and pumpkinseed	N	—	—	—	10	6	1	35	302	429	419	298
	M	—	—	—	7	8	12	13	72	208	259	130
Yellow bass	M	—	—	—	12	85	49	3	17	8	31	12
Black bullhead	N	—	—	—	52	1	3	22	3	3	6	1
	M	—	—	—	371	178	81	34	18	91	55	19

settled at that time; and further, the first week of seining is not so important to the growth estimates that it could not be eliminated during any single year if the data appeared to be nonrepresentative. Finally, 6 weeks were proposed as the basis of year-class-success estimates for ease of randomization and analysis since, with other qualifications, the Latin square model may then be used.

Seining has been restricted to 6:00 p.m. to 6:00 a.m. because such a restriction reduces the total effort by half and the larger catch per haul increases the efficiency of the effort.

Six stations have been proposed to allow the major habitat types to be sampled and to insure that an adequate sample of each species is collected each week. There are few locations at Clear Lake where space would permit more than two seine hauls of about 75 feet each to be made parallel and next to the shoreline. The six stations have been selected on the basis of the catches obtained at those stations in 1956 and 1957 with some consideration of their future seinability. Certain adjustments might be necessary with the proposed stations in relation to permanence and homogeneity, but once a series has been selected, changes should be made only after careful coonsideration of their effects.

Counts of all fish captured are required for estimates of year-class success. The number of fish measured is arbitrary, although it has been shown that 30 fish of each species measured each time a station was sampled generally yielded estimates of mean length which were considered precise enough for the purposes of this study. To obtain a different level of precision more or fewer fish may be measured depending upon the numbers captured and the variation encountered.

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The Bottom Fauna of Lake Huron[1]

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ABSTRACT

The examination of 63 bottom samples, collected in Lake Huron in 1952 and 1956, revealed that *Pontoporeia affinis* was the dominant organism in both deep and shallow water. The next most abundant organisms in deep water were oligochaetes, fingernail clams, and midge larvae. Midge larvae were more numerous than either oligochaetes or fingernail clams in shallow water. The number of organisms per square meter was similar to that determined from a similar study on Lake Michigan.

INTRODUCTION

Very little has been published on the bottom fauna of the Great Lakes. A number of qualitative studies or ones limited to specific groups have been published, but only three quantitative studies of open-lake conditions have appeared (Lake Erie—Shelford and Boesel, 1942; Wright, 1955; Lake Michigan—Eggleton, 1936, 1937). In each lake a single dominant organism outnumbered all others combined. In Lake Erie it was the larva of the mayfly *Hexagenia*. In Lake Michigan it was the amphipod *Pontoporeia*.

The present paper reports on 63 samples taken from 28 stations in Lake Huron (Figure 1) by the U. S. Bureau of Commercial Fisheries research vessel *Cisco* in 1952 and 1956. Although the samples are few for so large an area, the results agree well with Eggleton's from Lake Michigan.

METHODS AND EQUIPMENT

Twenty-five single samples were taken during September and early October 1952 (stations 198-230, Figure 1). Sampling depths ranged from 5.5 to 119 meters. Temperatures ranged from 4.2° C. to 7.1° C. in the deep-water samples (greater than 25 meters) and from 13.7° C. to 19.7°C. in the shallow-water samples (5.5 to 25 meters).

The other 38 samples were taken in 1956. One was a single sample (station 65) taken off Harbor Beach, Michigan, at a depth of 46 meters—temperature 4.9° C. The rest were multiple samples taken from stations 62 and 64 at intervals throughout the season from June 21 to October 27. Station 62, 33 meters deep, was in the mouth of Saginaw Bay. Bottom temperatures varied between 5.7° C. and 11.4° C. Station 64, also 33 meters deep, was off the east shore of the "thumb" of Michigan. Bottom temperatures ranged between 4.9° C. and 12.2° C. The bottom at both stations was mainly sand; some samples contained a little mud and others a little gravel.

All samples were taken with a Petersen dredge having a cross-section area of 737 square centimeters. The mud and fine sand were rinsed off through a screen of U. S. Sieve Series, No. 30 mesh. The organisms were recovered manually or floated out of the remaining sand in a saturated sucrose solution (specific gravity of 1.110) and preserved, one sample to a bottle, in 70 percent alcohol. The contents of each bottle were examined under binocular microscope and the individuals of each species counted. Results from the 2 years are not separated, since 1952 stations were not revisited in 1956. Consequently, there is no basis for an annual comparison.

LIST OF ORGANISMS

Organisms from 15 major taxonomic groups were present in the samples. Those marked with asterisks were found only in the 5.5- to 25-meter depth zone; others occurred at depths between 5.5 and 119 meters.

Hydra
Turbellaria—at least two species
Nematoda—at least two species
Oligochaeta
    Naidium sp.
    Limnodrilus claparedianus

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[2]Present address: Redford High School, Detroit, Michigan.

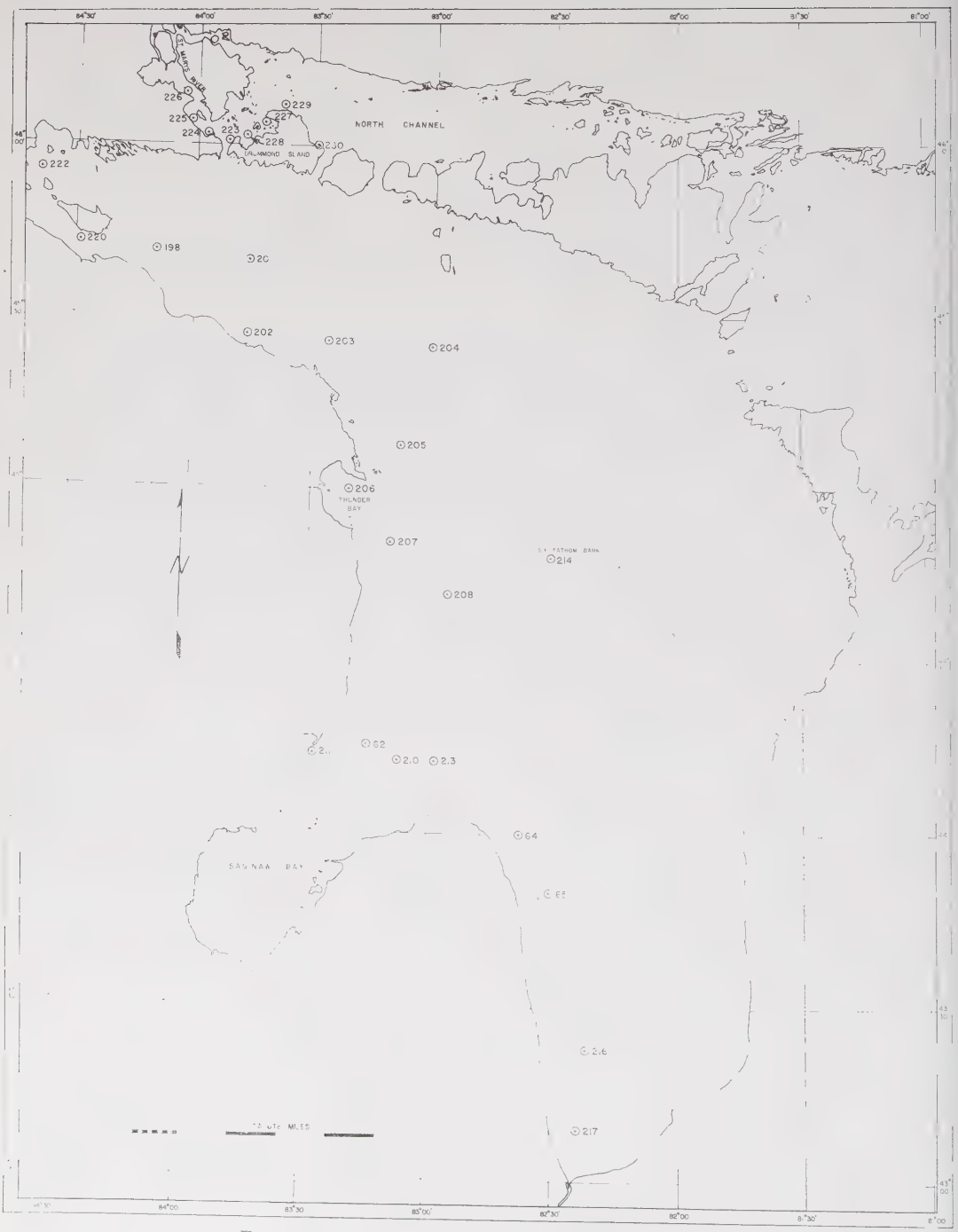

FIGURE 1.—Lake Huron showing principal stations.

Hirudinea
*Glossiphonia**
One unidentified
Pelecypoda
Pisidium
Sphaerium
Gastropoda
*Lymnaea**
Valvata
Ostracoda
Darwinula stevensoni
One unidentified
Isopoda
Asellus sp.
Lirceus sp.*
Amphipoda
Gammarus sp.*
Pontoporeia affinis
Mysidacea
Mysis relicta
Ephemeroptera
Hexagenia larvae*
Trichoptera larvae
Molanna sp.*
Polycentropus sp.*
Unidentified—at least two species*
Megaloptera
Sialis sp. larvae*
Diptera (Tendipedidae—one or more species of the following genera)
*Tendipes**
*Glyptotendipes**
Clinotanypus
Calopsectra
Procladius
Spaniotoma
*Cryptochironomus**
Polypedilum
Several unidentified

DISTRIBUTION AND ABUNDANCE OF DOMINANT ORGANISMS

Pontoporeia affinis was the dominant organism (Table 1). This amphipod constituted 31 percent of all specimens in the deep-water samples. It also occurred in reduced numbers in the shallower waters of the St. Marys River and the North Channel. It did not occur in areas of the same depth in Saginaw Bay[3] (not covered in this study). Wright (1955) did not find *Pontoporeia* in similar depths in western Lake Erie. It is possible that temperature rather than depth limits its distribution. Temperature records collected by the U. S. Bureau of Commercial Fisheries indicate that, although shallow, the water in the St. Marys River and North Channel is cooler than in Saginaw Bay. The extensive shallows of Saginaw Bay and western Lake Erie warm to rather high temperatures in summer.

Pontoporeia was carrying eggs in only one sample (station 65, August 3, 1956). In other samples it was possible to recognize a group of very small individuals of uniform size. They constituted 57 percent of all *Pontoporeia* in samples from station 64. At this station they were about 2 millimeters long in June and about 3 millimeters in October. The rest of the *Pontoporeia* were of various sizes, but all were distinctly larger than the numerous small individuals. In midsummer the volume of these larger *Pontoporeia* averaged about 10 times that of the small ones. Evidently *Pontoporeia* usually breeds once a year in Lake Huron and grows slowly. The major breeding season probably is in winter or early spring.

Oligochætes and fingernail clams, *Pisidium*, were next most abundant (Table 1). Only three of the 63 samples did not contain oligochætes.

[3]Unpublished records from a cooperative study of Saginaw Bay by the Bureau of Commercial Fisheries and the Michigan Department of Conservation.

TABLE 1.—*Average number of organisms per square meter in Lake Huron bottom samples, 1952 and 1956*
[Shallow-water stations were in depths of 5.5 to 25 meters inclusive; deep-water stations in depths of 25 to 119 meters.]

Group of stations	Number of stations	Number of samples	*Pontoporeia affinis*	*Pisidium*	*Limnodrilus hoffmeisteri*	*Nais* sp.	Midge larvae (*Tendipedidae*)	Midge pupae	Nematodes	All other organisms	All organisms
All stations	28	63	1,119	129	121	7	36	9	4	36	1,461
Shallow-water stations	11	11	334	65	35	6	77	23	4	81	625
All deep-water stations	17	52	1,627	170	176	7	9	0.5	6	7	2,002
Deep-water stations except 62 and 64	15	15	1,343	161	115	1	7	0	4	6	1,640
Station 62	1	11	2,018	35	398	1	16	4	2	7	2,481
Station 64	1	26	5,495	444	868	63	32	4	46	14	6,966

Pisidium was in all samples except eight. Numbers of these two groups were about equal. Cocoons of the worms were common throughout the summer, although relatively few newly-hatched worms were collected. They were probably lost in the original sorting. The counts of worms are little better than estimates, since the specimens usually were broken, sometimes into several pieces.

No attempt was made to separate *Pisidium* into species. Oligochætes, however, were identified by Eugene W. Surber who determined that there were but two species. The more numerous was *Limnodrilus claparedianus* Ratzel. The less abundant worm was a member of the genus *Naidium*, probably a new species. The fact that it has missed the attention of the taxonomists until now, even though it exists by the millions in Lake Huron and probably in the other Great Lakes, emphasizes how little work has been done in these important bodies of water.

Nematodes occurred in 26 samples (Table 1). Of course there may have been numerous microscopic nematodes which went through the washing screen.

The only insects taken in deep water were midge larvæ (Tendipedidæ), which occurred in about two-thirds of all samples. The number of individuals was generally small (Table 1), but the number of species was large. Eight genera were identified. Some of these probably included more than one species. Over 30 percent of all midge larvæ remain unidentified. An extensive study of this group might show species preferences for certain depths, temperatures, dissolved-oxygen concentrations, bottom types, or distances from shore. *Spaniotoma* and an unidentified midge were the only ones abundant in deep water. *Tendipes*, *Glyptotendipes*, and *Cryptochironomus* were taken only in shallow water.

Fewer than one-third of the deep-water samples contained any organisms other than in the above-mentioned five groups. Among those collected were partially pelagic forms (*Mysis relicta* and ostracods) caught by chance in the dredge. The shallow-water samples contained more types. Small fragile specimens were undoubtedly lost in sorting the organisms from the sediments. Statoblasts were found in some samples but not a single bryozoan. *Hydra* occurred in one sample from station 64.

One very curious sample (227), taken from 5.5 meters off the west shore of Drummond Island, contained the isopod, *Lirceus*, the mayfly, *Hexagenia*, and midge larvæ instead of the usual *Pontoporeia*, oligochætes, and *Pisidium*. The estimated numbers per square meter were: 535 isopods, 108 midge larvæ, and 68 *Hexagenia*. A few caddis-fly (*Molanna*, *Polycentropus*) and alderfly (*Sialis*) larvæ were taken.

COMPARISON WITH BOTTOM FAUNA OF LAKES MICHIGAN AND ERIE

The average number of animals per square meter for all stations of 1952 and 1956 was 1,461 (Table 1). If data from the two more productive stations (62 and 64) are not included in calculation of the average, then the figure is 1,211 per square meter. This value approximates the average number of organisms per square meter in Lake Michigan. The means of the monthly averages presented by Eggleton (1937) give values of 1,242 and 1,150 animals per square meter for 1931 and 1932, respectively.

The high productivity at stations 62 and 64 may be the result of flow of the rich waters of Saginaw Bay into the vicinity of these stations (Beeton, 1958). Station 64 was unusually productive (Table 1). The only other station approaching the productivity of stations 62 and 64 was 214 near the Six Fathom Bank. The greatest concentration of organisms was in one sample taken at station 64 on October 5, 1956. It contained 10,556 organisms per square meter. Eggleton (1937) reported a maximum of 11,440 animals per square meter.

The number of animals per square meter in the deep water (25-119 meters) of Lake Huron, excluding stations 62 and 64, was 1,640 (Table 1). The number of organisms per square meter in the combined 1931-32 Lake Michigan samples from 20-119 meters was 1,635 (this figure is the mean for this depth interval—Eggleton, 1937).

The organisms per square meter were fewer in the shallow-water samples—average 625 (Table 1). This figure approximates the average of 587 animals per square meter in the shallow west end of Lake Erie in 1930 (Wright, 1955—figure is the average of the means for various organisms). The shallow waters of Lake Huron, however, were un-

doubtedly much less productive than those of Lake Erie in terms of biomass, since large organisms, especially *Hexagenia*, were more plentiful in the Lake Erie samples.

Seasonal changes in the abundance of organisms, such as noted by Eggleton (1937) in Lake Michigan, were not observed at station 64, although sampling was conducted once or twice a month from June through October.

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Some Consequences of Adding Fertilizer to Five Michigan Trout Lakes[1]

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ABSTRACT

Inorganic fertilizer was applied to four of a group of six Michigan trout lakes. The thermocline in the three lakes receiving the most fertilizer shifted to a more shallow position. Three of the fertilized lakes decreased in total alkalinity at a greater rate than did the two lakes not fertilized. Fertilization resulted in the oxygen being depleted from the hypolimnion and some oxygen reduction occurred in the thermocline. The volume of oxygenated water remaining under the ice during the critical period of late winter was reduced in the fertilized lakes, and lakes fertilized at the highest rate very nearly approached winterkill conditions. The reduction of oxygen both in summer stagnation periods and in late winter was more severe after the second season of fertilization.

INTRODUCTION

The energy from the sun and the allogenic inorganic and organic nutrients from the surrounding soils provide the basis for the complex of biological activity within a lake basin. Ricker (1946) suggests two methods of approach to increase fish yield from a lake. Nutrient material can be added artificially to induce greater production, or more efficient use of the existing nutrient supply may be encouraged.

Artificial enrichment to increase the yield of fish from a body of water is not a new idea. Pond fertilization has been practiced in the Orient since early in recorded history.[2] Neess (1949), in reviewing practices of pond culture, noted the use of fertilizers in Central Europe several centuries ago. In spite of its antiquity, pond fertilization in this country is relatively new. The development of farm ponds and the pioneer work with fertilizers began in the southern states during the 1930's (Hogan, 1933; Meehean, 1933; Swingle and Smith, 1939). From this beginning, the practice of fertilization has spread throughout the United States and Canada and applications have been tried on a variety of aquatic habitats.

In Michigan an experimental fertilization program was begun in 1946 and has encompassed many types of waters. One group of studies has included the fertilization of natural lakes. Hasler (1947), in discussing the advisability of fertilizing natural waters, pointed out the absence of complete information on the effects of artificial enrichment and the need for further experimental work. When the present study was begun in June 1948, certain information from completed experiments served to guide the direction of the program. Heavy applications of fertilizer to a warm-water lake and to a trout lake had created winterkill conditions in both lakes after two summers of treatment (Ball, 1948; Ball and Tanner, 1951).

Evaluation of creel-census reports has emphasized that catch by fishermen often fails to harvest warm-water species adequately, and therefore increasing populations of these fish by fertilization seldom can be justified economically. For the above reasons landlocked oligotrophic trout lakes in which the rate of harvest has been shown to be high (Eschmeyer, 1938) have been selected as the type of natural water most likely to justify a fertilization program.

Some workers feel that artificial enrichment of natural lakes is unwise (Hasler, 1947; Hasler and Einsele, 1948; Hayes, 1951), especially in water areas with population of salmonid or coregonid fishes which need cold, well oxygenated water.

Hayes (1951) opposes the use of fertilizers because: (1) the addition of nutrients to a lake speeds the process of eutrophication and extinction; (2) the eutrophication of a lake

[1]This study was supported by the Institute for Fisheries Research of the Michigan Department of Conservation with a doctorate fellowship.

[2]Drews, Robin A. (1951) The cultivation of food fish in China and Japan; a study disclosing the contrasting national patterns for rearing fish consistent with differing cultural histories of China and Japan. Ph. D. Thesis, Univ. of Michigan (unpublished).

favors less desirable species of fish and results in the elimination of trout; and (3) the influence of added nutrients is of short duration and continual fertilization is necessary. Hasler (1947) noted the consequences of inadvertent enrichment of lakes in Europe with accompanying disastrous results to the trouts and whitefishes and concluded that a continuing addition of nutrients to American trout lakes would have similar results.

While other studies have shown general increases in productivity following application of fertilizer, the effects on the various trophic levels and on the chemical and physical environmental factors have remained unpredictable. The present study was designed, therefore, to examine some of the secondary effects of enrichment on the chemical and physical features of the environment.

DESCRIPTION OF THE STUDY AREA

A group of six trout lakes in the Pigeon River State Forest was chosen for the present study. These lakes, known as the Pigeon River "Pot-Hole" Lakes, were selected because they were small in area, close to one another, located on state-owned lands, and were generally similar. Five of the six are in Otsego County (North Twin, South Twin, West Lost, Lost, and Section Four lakes) and Hemlock Lake is nearby in Cheboygan County. Two of the lakes had been used in a fertilization experiment by Ball (1948). The immediate area in which the lakes are located has been designated as the Pigeon River Trout Research Area and is under the administration of the Michigan Institute for Fisheries Research.

The unusual physical characteristics of these six lakes with their nearly symmetrical outline, the water surface 40 to 60 feet below the surrounding terrain, and with the exception of Hemlock, the steepness of the slopes which surround each lake, have created considerable interest in their origin. Some geologists who are familiar with the region and the lakes consider them to be limestone sinks.

In general, the physical and chemical characteristics of the six lakes are similar (Table 1), but there are certain important differences. The extent of shoal area ranged from 15 percent in South Twin Lake to 4 percent in Section Four Lake. The Secchi-disk readings were approximately 36 feet in Section Four Lake and only 11 feet in Hemlock Lake. Section Four Lake was the deepest with a maximum depth of 72 feet and South Twin Lake the most shallow with a maximum depth of 34 feet.

South Twin Lake has beds of aquatic vegetation consisting of *Potamogeton amplifolius* at depths from 7 to 18 feet. In terms of methyl orange alkalinity, North Twin Lake was the softest with an average in the lower epilimnion of 32 p.p.m. and Section Four Lake was the hardest with an average of 192 p.p.m. The bottom soils of South Twin, North Twin, and West Lost lakes are sand in the shoal and sub-littoral regions with peat in the depths. West Lost Lake has small amounts of marl present. Lost, Hemlock, and Section Four lakes are considerably deeper marl lakes with varying amounts of peat present in the depths.

MATERIAL AND METHODS

The summer of 1948 was spent in collecting pre-fertilization data and poisoning of those lakes which contained trash fish. Fertilizer was applied to four of the lakes during the

TABLE 1.—*Physical and chemical characteristics of the study lakes prior to fertilization*

Lakes[1]	Surface area (acres)	Depth (feet)		Bottom soil type			Methyl orange alkalinity	Secchi-disk reading (feet)	Thermocline	Percentage shoal[2]	Aquatic vegetation
		Maximum	Average	Shoal	Sub-littoral	Profundal					
South Twin	3.9	34	24	sand	peat	peat	74	12.7	12-30	15.3	extensive
North Twin	4.7	44	28	sand	peat	peat	32	15.1	15-36	13.0	limited
West Lost	3.7	44	29	sand	peat[3]	peat	138	23.7	18-33	11.0	rare
Lost	3.5	55	41	marl	marl	peat marl	177	17.0	18-33	3.3	rare
Hemlock	5.9	64	41	peat marl	peat[3]	peat	163	11.1	12-30	4.2	limited
Section Four	2.6	72	51	marl	marl	peat marl	192	35.7	18-42	4.0	rare

[1]All landlocked except Hemlock, which had an old outlet that has not flowed since prior to 1932.
[2]Shoal and littoral zone are considered synonymous.
[3]Small amounts of marl present.

summers of 1949 and 1950, and the remaining two served as controls. Data were collected to facilitate comparison of physical, chemical, and biological conditions before and during the period of fertilization. The study was terminated at the end of the summer of 1950 when the lakes were again poisoned to obtain estimates of the trout population.

Investigation of the problem of winterkill necessitated chemical examination of the lakes each winter during the period believed to be the most critical. A trip during February 1951 was the last date of collection.

North Twin, South Twin, West Lost, and Section Four lakes were poisoned in 1948 to remove undesirable populations of the warm-water fish. Temperature readings were taken in each lake at weekly intervals throughout the three summers of the field investigation. Observations were made from top to bottom in order to establish the position of the thermocline and after it was located chemical analyses of the water from the mid-epilimnion, the mid-thermocline, and the mid-hypolimnion were made. Additional samples were taken at 3-foot intervals to determine at what point the levels of dissolved oxygen fell below 4 p.p.m. It was belived to be important to determine whether or not oxygen supplies in the thermocline during the midsummer stagnation period were reduced below the levels necessary for trout survival. The thermocline at this period is often the only region of these lakes suitable for trout from the standpoint of temperature and oxygen.

After removal of trash fish populations from four of the lakes in 1948, brown trout *(Salmo trutta)* were stocked in all six lakes. The brown trout was selected because it was felt to be least vulnerable to angling.

During 1946 and 1947 South Twin Lake (3.9 acres) was treated with inorganic fertilizer (10-6-4) five times during each summer. In 1946, 400 pounds were used for each application. Since this treatment failed to produce more than a moderate increase in phytoplankton, 600 pounds per application were used during the summer of 1947, to make a total of 5,000 pounds for both seasons. A winterkill occurred during the winter of 1947-1948 which could be attributed directly to the addition of fertilizer (Ball, 1948). In view of Ball's results four of the six experimental lakes were fertilized at reduced rates (Table 2). They were fertilized at different rates to determine whether a rate of application low enough to avoid winterkill is high enough to be reflected in increased growth of trout. The greatest amount of fertilizer was added to the lake with the greatest total alkalinity, Section Four Lake, and the softer water lakes received fertilizer at lower rates.

TABLE 2.—*The rate of fertilizer application to the six study lakes, 1949-1950—expressed as total pounds and parts per million*

Lakes	Pounds		Total[2] p.p.m.
	1949	1950	
Section Four	1,700	1,272	15.0
Lost	1,725	1,275	11.4
Hemlock	1,570	1,230	6.4
West Lost	400	300	3.9
North Twin	0	0	0
	1946	1947	
South Twin[1]	2,000	3,000	28.5

[1]Fertilized by Ball (1948).
[2]For the two summers.

The phytoplankton is most responsive to added nutrients and the extent of this response has been used as an index of changes in biological activity (Swingle and Smith, 1939). Secchi-disk readings taken weekly in 1948, 1949, and 1950 were used as a chronological record of the changes in amounts of seston present. It has been shown (Chu, 1943; Van Deusen, 1947[3]) that Secchi-disk readings provide a reasonably accurate estimate of major changes in amounts of suspended matter. Plankton samples were collected periodically for species identification.

CHANGES INDUCED BY FERTILIZATION

Thermocline

The thermoclines of the fertilized lakes (West Lost, Lost, Hemlock, and Section Four) appear to have been more shallow in 1949 and 1950, the fertilized period, than in 1948, prior to fertilization (Table 3). In North Twin and in South Twin lakes (unfertilized) the thermoclines showed very little change during the same period. An analysis of variance of the midpoints indicated that the thermoclines of the three lakes receiving

[3]Van Deusen, R. D. (1947) Quantitative and qualitative evaluation of plankton from fertilized and non-fertilized hatchery ponds, with an appraisal of methods used. M. S. Thesis, Michigan State College (unpublished).

TABLE 3.—*Average depth of the thermocline midpoints in fertilized and unfertilized lakes—expressed in feet*

Lakes	1948	1949[1]	1950[1]
Unfertilized			
North Twin	25.1	28.0	26.7
South Twin	21.6	24.6	21.2
Fertilized			
West Lost	25.8	26.0	23.4
Hemlock	22.0	15.2	14.9
Lost	25.6	21.5	22.4
Section Four	30.1	27.6	21.0

[1]Period of fertilization.

the largest applications of fertilizer (Hemlock, Lost, and Section Four) were significantly more shallow during 1949 and 1950 than in the previous year. No significant change occurred in the average position of the thermoclines in North or South Twin, the unfertilized lakes, or in West Lost Lake, which received the least amount of fertilizer.

The change in position of the thermocline was probably due to increased density of the plankton population. Clarke (1946) showed that the depth of light penetration was frequently dependent on the amounts of plankton present. Since an increase in plankton occurred in the fertilized waters, light and heat did not penetrate to the depth that they did prior to fertilization but were absorbed near the surface. The water of the hypolimnia remained at temperatures only slightly above 4° C., and the sheltered position of the lakes permitted the establishment of the thermocline in a shallow position.

Oxygen depletion

The addition of fertilizer to lakes may reduce the amount of dissolved oxygen (Ball, 1948). During the present study attention was given to the detection of changes in the oxygen content of the lakes. The average depth at which the amount of dissolved oxygen fell below 4 p.p.m. was determined by weekly observations during each summer of the investigation. The amount of oxygenated water present during the summer stagnation period was reduced in the fertilized lakes while little or no reduction occurred in the unfertilized lakes (Table 4, Figure 1).

An analysis of variance was applied to the data from each lake to determine if there was a significant difference in the amounts of oxygenated water present in the pre-fertilization period and during the fertilization period. The amount of oxygenated water present during the period of fertilization in the fertilized lakes was significantly less than before fertilization. There was no change in the unfertilized lakes during the same period. On the basis of these analyses it was concluded that the oxygen reduction was caused by fertilization. In general, the summer oxygen reduction occurred only in the hypolimnion. Kusnetzow (1939) found that the respiration of bacteria is the primary agent of oxygen reduction in the hypolimnion. The added nutrients increase the biological production and the dead organic matter which sinks into the hypolimnion. Increased bacterial action results in a more rapid oxygen depletion during the summer stagnation period. The average amounts of oxygenated water present during the two summers of fertilization have been compared with the average amount present during the summer prior to fertilization (Figure 1). Oxygen levels during the pre-fertilization period have been assigned the value of 100 percent. The percentage of oxygenated water remaining during the period of fertilization is indicated by the graph. In general, the more fertilizer that was added the greater was the reduction of oxygenated water. The amount of oxygen depletion in Section Four Lake was slight during the first summer of fertilization in spite of the fact that it was receiving the most fertilizer. The large volume of the hypolimnion in relation to the surface and littoral areas may explain the lag in the oxygen reduction in the hypolimnion.

In South Twin Lake a slight reverse trend was observed. It was fertilized during the summers of 1946-1947, and in 1948 there was a considerable volume of water in the thermocline and below in which there was less than 4 p.p.m. of oxygen. These observa-

TABLE 4.—*Average depth at which oxygen content fell below 4 p.p.m. during summer months in various years—expressed in feet*

Lakes	1948	1949[1]	1950[1]
Unfertilized			
North Twin	35.5	37.1	35.3
South Twin	27.0	30.7	28.7
Fertilized			
West Lost	37.1	29.0	29.0
Hemlock	27.1	20.0	18.4
Lost	49.5	35.3	30.5
Section Four	59.9	54.7	33.2

[1]Period of fertilization.

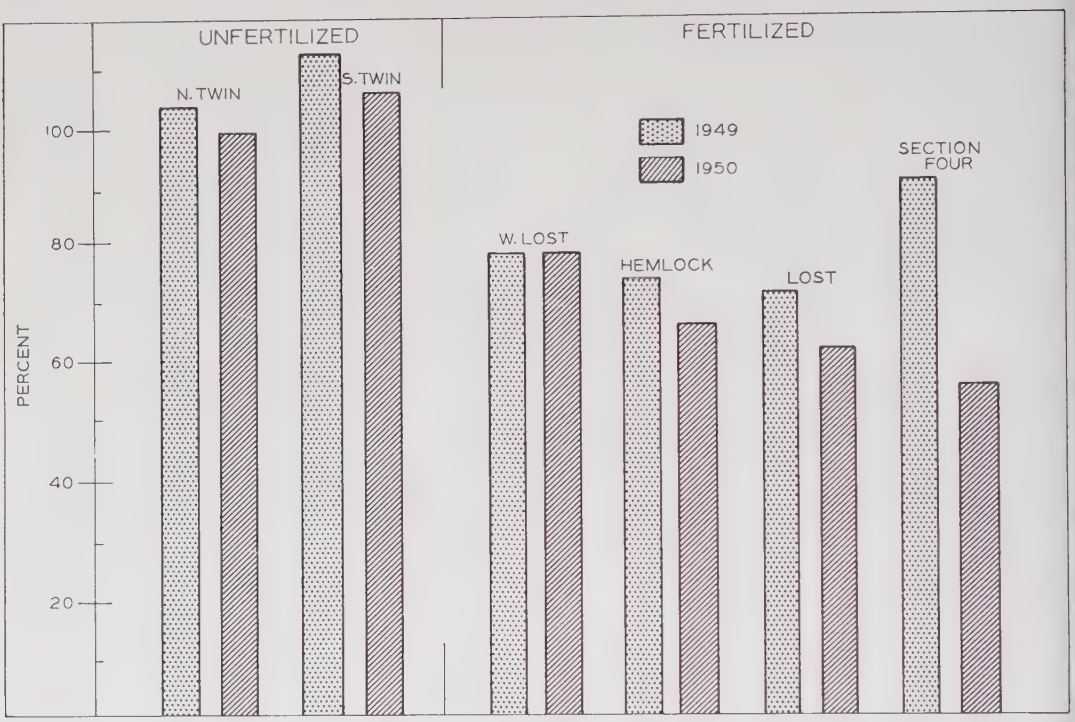

FIGURE 1.—Depth of oxygenated water remaining during the two summers of fertilization, expressed as percentage of that present in the pre-fertilization period.

tions indicate a carry-over of the effects from fertilization in previous summers.

In most Michigan trout lakes the trout are confined for a portion of the summer to the thermocline by excessive water temperatures in the epilimnion and by lack of oxygen in the hypolimnion. The importance of changes in position of the thermocline (Table 3) and changes in the volume of oxygenated water under a regimen of fertilization, is determined by resulting changes in the water area available to trout during the summer growing period. Throughout the three summers surface and epilimnion temperatures, in both the fertilized and the unfertilized lakes, were not restrictive. The surface temperatures occasionally reached, but did not exceed, 76° F. The average depth of the 4 p.p.m. dissolved-oxygen isopleth was used to delineate the areas available or unavailable to the trout population. It is concluded from these data (Table 4, Figure 1) that fertilization reduced the volume of water available to the trout population in the summer by 20 to 40 percent. Had the temperature in the epilimnion been restrictive the loss of available area would have been even greater.

There is another evaluation of the importance of the removal of oxygen from the hypolimnion. Einsele (1938) has indicated that in general, when iron is present in the hypolimnion, it combines with phosphorus as ferric phosphate in the presence of oxygen. The precipitate formed is insoluble and results in the removal of phosphorus from the lake water. If, however, oxygen is absent when the iron and phosphorus combine, the product is a soluble ferrous phosphate, some of which will be reused and not lost to the lake. Mortimer (1941) has indicated that the processes of reduction usually return the nutrient material in forms more usable by plants and bacteria than do the processes of oxidation. Eutrophication is extremely slow while the lake is oligotrophic. When the lake assumes the characteristics of a eutrophic lake, which include lack of oxygen in the hypolimnion during the summer stagnation period, continued eutrophication and extinction become rapid. As Mortimer points out, the differences in the products of oxidation and reduction probably account for this sudden quickening of the rate at which a lake becomes extinct.

Changes in the fish population of a lake due to oxygen depletion during the summer stagnation period are long-term ones and the final effects may take several years to evaluate. Winter oxygen depletion with consequent winterkill, however, is an immediate change and the results usually are plainly discernible.

Oxygen levels at the time when snow and ice had been on the lakes for the longest period are presented in Table 5. They are expressed as the depth in feet at which oxygen supplies fell below 2 p.p.m. Some oxygen depletion occurred in all the fertilized lakes, and in Section Four Lake which received the most fertilizer the amount of oxygenated water remaining was only 4 feet in depth on February 26, 1951. Since this observation was the only one and conditions may have deteriorated before spring, winterkill conditions may have occurred later and remained undetected because there was an absence of fish. It must be concluded that the rate at which fertilizer was applied to Section Four Lake was excessive.

TABLE 5.—*Depth at which oxygen content fell below 2 p.p.m. during winter months—expressed in feet*

Lakes	1949	1950[1]	1951[1]
Unfertilized			
North Twin	—	27	27
South Twin	12	8	23
Fertilized			
West Lost	27	18	22
Hemlock	22	11	18
Lost	35	30	24
Section Four	—	36	4

[1]Period of fertilization.

In the other lakes winterkill conditions apparently were not approached. The small amount of fertilizer applied to West Lost Lake did not create conditions approaching a winterkill and probably could be used elsewhere on similar lakes without endangering fish life. The observations also indicate that oxygen reduction due to fertilization tends to increase as treatment is continued (Table 5). This trend is also discernible in the data on the summer oxygen levels (Table 4).

South Twin Lake, which was fertilized heavily in 1946 and 1947 and winterkilled during the 1947-48 season, was observed carefully in order to detect any residual effect of fertilization on winter oxygen levels. The oxygen depletion during the winters of 1949 and 1950 was severe, while in 1951 the volume of oxygenated water in South Twin Lake was comparable to the amount present in the unfertilized North Twin Lake (Table 5). It was concluded that the oxygen reduction during the winters of 1949 and 1950 was a residual effect of fertilization.

Changes in alkalinity

Determination of methyl orange alkalinity was made weekly. In comparing the average alkalinity on pre-fertilization dates with that during fertilization (Table 6) it is apparent that there was a reduction of alkalinity in each of the six lakes during the 3 years of the study. The rate of reduction appeared to be greater in the fertilized lakes than in North Twin and South Twin, the unfertilized lakes.

To determine whether there was a real difference in the rate of reduction in alkalinity between the fertilized lakes and unfertilized lakes during the period of fertilization the average alkalinity of each lake during the pre-fertilization period and during the period of fertilization together with the standard error of their means were calculated. The value for the average total alkalinity of the fertilization period was then divided by the figure for the pre-fertilization period. Since all the lakes were less alkaline during the period of fertilization than previously, the quotients were less than one (Table 6). The standard error of the quotient was used to determine confidence limits. The quotients and plus and minus twice the standard error of each were plotted (Figure 2). This graphic method of statistical presentation, with some exceptions (Dice and Lerass, 1936), enables

TABLE 6.—*Rates of reduction in total alkalinity in the unfertilized and fertilized lakes during the fertilization period*

Lakes	Average total alkalinity		Quotient[1]	Standard error of quotient
	1949-1950	1948		
Unfertilized				
North Twin	29.5	31.7	0.930	0.016
South Twin	67.8	74.0	0.916	0.033
Fertilized				
West Lost	120.3	137.1	0.875	0.010
Hemlock	117.7	161.3	0.730	0.009
Lost	126.2	177.5	0.713	0.010
Section Four	153.0	191.9	0.798	0.006

[1]Ratio of 1949-1950 average to 1948 average.

one by observation to determine if a significant difference exists. Exceptions occur when overlapping is slight or very closely approached. In these instances t tests must be employed (Walker, 1943). Hemlock, Lost, and Section Four, the lakes receiving the heavier applications of fertilizer, were reduced in alkalinity at a rate which was greater (highly significant) than for the two unfertilized lakes, North and South Twin (Figure 2). West Lost Lake was fertilized

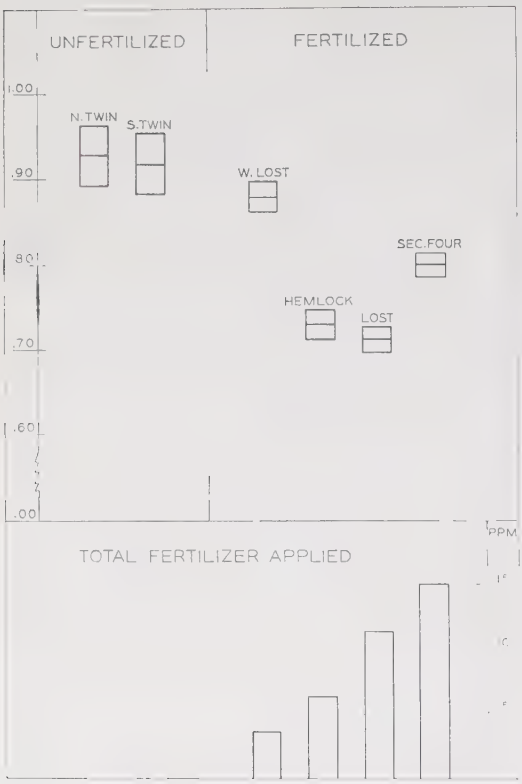

FIGURE 2.—The quotients obtained by dividing the average total alkalinity during fertilization by average total alkalinity prior to fertilization for each lake. Graphed with ± twice the standard error of the quotient. Fertilization rates indicated by graph at base of chart.

very lightly and did not differ significantly from South Twin Lake, but was different from North Twin Lake.

The increased biological activity which occurred following the application of fertilizer was apparently the cause of the decrease in total alkalinity. The increase in the phytoplankton resulted in an increase in the demand for carbon for the synthesis of carbohydrates during photosynthesis. In addition, the sudden reduction of the carbon dioxide in the water may have reduced the solubility of carbonates in the water and caused their precipitation (Huber-Pestalozzi, 1938). These factors singly or in combination resulted in a decrease in total alkalinity.

IMPLICATIONS FOR MANAGEMENT

Previous studies have indicated that the usefulness of fertilizer in natural lakes to increase fish production may be limited by undesirable changes in the environment or by economic considerations. The winterkills which followed heavy application of fertilizer to lakes in the same part of the state where these experiments were conducted (Ball, 1948; Ball and Tanner, 1951) appear to be the most serious adverse results of fertilization. Winterkill conditions were not produced by low rates of application, but some oxygen reduction occurred and was related directly to the amount of fertilizer added. The highest rate of application nearly caused winterkill conditions following the second summer of fertilization. The effects of fertilization are cumulative from year to year and new applications should not be made until the effects of the previous ones can no longer be detected. On the basis of conditions in the one lake of the group which had been fertilized during 1946 and 1947, the duration of the increased biological activity and reduction of oxygen may be 3 or more years. Summer oxygen reductions occurred in the four fertilized lakes, and by the end of the second summer little oxygenated water remained below the thermoclines. The importance of the elimination of oxygen from the hypolimnia as a milestone in the eutrophication and extinction of lakes has been pointed out by Einsele (1938). The oxygen reduction was not severe in the thermocline. The shift of the thermocline to a more shallow position as a direct result of fertilization combined with the removal of oxygen from the hypolimnion reduced the amount of water available to the trout during the midsummer period.

South Twin Lake, which was fertilized in 1946 and 1947, was observed throughout the study to evaluate the residual effects of fertilization. The extent of the eutrophication occurring as a result of fertilization is considerable. Because it increases the rate of eutrophication and hastens the extinction of a

lake, fertilization cannot be justified in most instances. It has been pointed out, however, that there are lakes in Michigan that are suited for trout except that the amount of food present will not support enough fish to sustain a heavy fishing load. In instances where fertilization creates a new source of fishing it should be considered as a practical and ethical approach to management of unproductive lakes. Two lakes, Section Four and Lost, in the present study are lakes in this classification. The excellent fishing and high production in Section Four Lake shows that fertilization can create new fishing in lakes of very low productivity.[4]

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Digestion Rate and Food Consumption of Florida Gar, Warmouth, and Largemouth Bass[1]

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ABSTRACT

Voluntary- and force-feeding experiments were conducted on 131 Florida gar *(Lepisosteus platyrhincus)*, 46 warmouth *(Chaenobryttus gulosus)*, and 21 largemouth bass *(Micropterus salmoides)* to determine the rate of digestion and food consumption. The digestion rate of the warmouth was 1.6 times greater than that of the gar, and that of the bass was 1.5 times greater than the warmouth and 2.4 times greater than the gar. The daily voluntary food consumption of the warmouth was 1.6 times greater than the gar, and that of the bass 1.6 times that of the warmouth and 2.5 times greater than the gar.

INTRODUCTION

Although the Florida gar (*Lepisosteus platyrhincus*) is abundant in the Tamiami Canal, west of Miami, and other waterways in South Florida, little is known about its life history, habits, and relationships to other fishes in these waters. The Tamiami Canal contains very large populations of gar, bowfin, largemouth bass, other centrarchids, bullheads, and many other species of fish. The sizes of the populations are not known since no complete inventories have been made. A measure of the abundance of gar and bowfin (*Amia calva*), however, was obtained during June, July, and August, 1955, when approximately 45,000 pounds of these fish were removed by electro-fishing as part of an experimental rough fish removal program.[2] The author's calculated estimates, based on data presented in O'Connell's report, show that an average of 713 pounds per acre of gar and bowfin were removed from an 8-mile section of the canal. By weight, the gar composed only 25 percent of the catch and bowfin constituted the remainder, but numerically the gar exceeded the bowfin. In addition to these two species there is an unmeasured but large number of other fishes.

Published data on gar obtained for food studies have shown that from 45 to 80 percent of the fish had empty stomachs when captured (Coker, 1930; Scott, 1938; Lagler, Obrecht, and Harry, 1943; Hunt, 1953). The writer found that the volume of food in the stomachs of 106 gar obtained in 1952 averaged only 1.6 cubic centimeters and in most cases was considerably less than 1 cubic centimeter. In almost all of these stomachs the contents were in an advanced state of digestion. The large number of empty stomachs and the small quantity of food present raised questions concerning the food consumption and the rate of digestion in the gar. These findings suggested that perhaps the gar fed at irregular intervals, consumed comparatively small amounts of food, and digested it slowly.

In order to obtain information on these points, laboratory studies were conducted during the spring of 1958 and 1959 to determine the rate of digestion and the amount of food consumed by these fish. For comparative purposes, warmouth (*Chaenobryttus gulosus)* and largemouth bass *(Micropterus salmoides*) were subjected to the same experimental procedures.

METHODS

Fish were obtained from the Tamiami Canal and transported immediately to the laboratory. All gar were captured by means of a large dipnet, and most of the warmouth and bass were taken on an artificial fly. All fish were held, singly or in groups, in aerated aquaria with a capacity of 53 gallons. The water volume, however, was usually about 40 gallons. About 2 inches of coarse sand and

[1]Contribution No. 33 from the Ichthyological Laboratory and Museum, Department of Zoology, University of Miami.

[2]O'Connell, Timothy R., Jr. (1958) Experimental electrical fishing gear development. Florida Fresh Water Fish and Game Department. (Mimeographed)

several *Vallisneria* plants were placed on the bottom of each tank. The fishes appeared to adjust rapidly to the new environment provided by these large containers.

All fish used in experiments on rate of digestion were held without food for 2 or more days before they were fed. Since it was necessary to force feed the gar, the warmouth and bass were treated in the same manner to equalize the effect of handling. Bass and warmouth were easily fed manually, but the mouths of the gar had to be held open by a wooden spreader while the food articles were inserted in the gullet. This handling apparently had little if any adverse effect since data obtained from 13 warmouth, which had consumed the measured meal voluntarily, did not differ from those obtained by force feeding. At intervals the fish were sacrificed and the content of the stomachs was examined and measured. Digestion was judged to be complete when the stomach was clear of measurable food remains. Fish were individually identified by clipping fins.

The eastern mosquitofish *(Gambusia affinis holbrooki)* was the principal food item fed to these fish, although the sailfin molly (*Mollienesia latipinna*) was used on a few occasions when the former were scarce. Measurements of the meals and the partly digested food recovered from the stomachs were obtained as volume by water displacement. The relationship between volume and weight was established by making a volume and a weight measurement of each of 57 whole *Gambusia* and of material recovered from 29 gar stomachs. Comparison showed that although the volume measurement was consistently higher than the weight, the difference was less than 3 percent. Since the factor for converting 1 gram to 1 cubic centimeter was 1.026, it was decided that for the purposes of this study volume was the equivalent of weight.

In the comparative feeding experiments, 5 *Gambusia*, with a total volume of 2.5 cubic centimeters (= 2.5 grams), were fed to each fish. This size meal appeared to be the largest which could be hand fed in a reasonably short time and without undue forcing, particularly in the case of the warmouth. Preliminary experiments indicated that the time interval required to digest this quantity of food was convenient for expressing the results obtained from all three species of fish.

In the voluntary feeding experiments, a single fish was kept in each aquarium. A counted and measured group of *Gambusia* was offered to the fish whenever a previous group had been consumed or the numbers reduced to three or four. Food consumption of each individual was recorded.

Although temperature of the aquarium water varied between 23° C. and 26° C. while this study was in progress, it usually ranged between 24° C. and 25° C. Markus (1932) and Baldwin (1957) have demonstrated that temperature changes of 4° C. appreciably affect the rate of digestion; therefore the experiments were terminated each spring when the average daily water temperature exceeded 26° C.

FORCE FEEDING

Gar — Single-unit meal

In preliminary experiments 38 gar were fed one *Gambusia* each. Gar used in this experiment ranged from 270 to 325 millimeters in total length and from 70 to 132 grams in weight, with an average of 308 millimeters and 110 grams, respectively. *Gambusia* fed to these fish ranged from 0.5 to 1.3 grams in weight, with an average of 0.8 gram, which was equivalent to 0.73 percent of the average body weight of the gar.

It was obvious soon after feeding began that the rate of digestion varied greatly among individuals even in fish of the same size and fed the same sized meal. Large fish often digested food much more slowly than smaller ones. The following range of percentage of food digested at the end of various time intervals and the number of gar involved illustrates the typical variability encountered: 7 hours (4 fish), 8 to 28 percent; 13 hours (4 fish), 31 to 63 percent; 16 hours (6 fish), 38 to 80 percent; and 23 hours (4 fish), 69 to 94 percent. Plotting time and the percentage of food digested suggested a linear relationship, and a linear regression calculated by the method of least squares indicated that the average fish would completely digest the average meal in 25 hours. The shortest and longest observed interval for a meal to be completely digested was 20 and 27 hours, respectively. The average rate of digestion in this group of gar was 0.025 percent of the body weight per hour.

Gar — Multiple-unit meal

A total of 88 gar were successfully fed multiple-unit meals. These specimens ranged in total length from 270 to 333 millimeters with an average of 299 millimeters, and in weight from 71 to 119 grams, with an average of 95 grams. Most of them were between 80 and 110 grams in weight. The meal fed to these fish (2.5 grams) constituted from 2.10 to 3.52 percent of the individual body weights. The average food-body weight relationship was 2.63.

Specimens were sacrificed at intervals between 3 and 50 hours after being fed. Table 1 shows the range and average percentage of digestion at times when a considerable number of records were available. Other scattered records have not been included. A regression line (Figure 1) showing the relationship between percentage of food digested and time was determined and the appropriate values are given in the table.

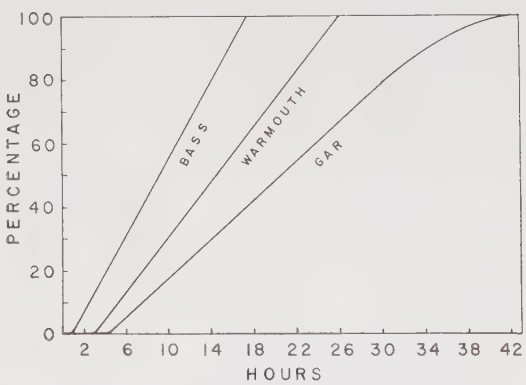

FIGURE 1.—Percentage of standard meal digested by largemouth bass, warmouth, and Florida gar in relation to time. These lines of best fit were calculated from empirical data.

Individual variation in the time required to digest a meal became very pronounced as the terminal period approached. It took as little as 28 hours to digest 90 percent of the meal in the fish with the most rapid rate of digestion and as much as 46 hours in the fish with the slowest rate. No measurable loss in volume of the stomach contents by digestion could be ascertained until food had been in the stomach more than 4 hours. In two instances no measurable digestion had occurred after 6 hours, although some loss of skin and scales was evident. The shortest observed time in which complete digestion occurred was 32 hours and the longest that some food remains were present was 47 hours, at which time three fish still contained from 1 to 6 percent of the original meal. Three fish examined 48 to 50 hours after feeding were empty. The average time required to digest 100 percent of the food and for the stomach to empty was calculated to be 42 hours.

TABLE 1.—*Percentage of food digested by Florida gar at selected time intervals*

Hours after feeding	Number of fish	Percentage of food digested		
		Range	Mean	Calculated regression average
0 - 4	3	0	0	0
6 - 7.5	8	0 - 10	6	7
15 - 16	7	19 - 40	26	34
19 - 20	7	40 - 71	51	47
25 - 26	6	46 - 80	63	65
29 - 30	22	56 - 98	75	79
36 - 40	8	74 - 100	90	97
44 - 47	9	91 - 100	97	100+

Individual digestion rates, based on percentage of body weight of food digested per hour in fish sacrificed more than 10 hours after feeding, ranged from 0.029 to 0.103, with an average of 0.056. No significant difference in rates could be ascertained between the larger and smaller fish of the sample.

The difference between the rate of digestion, based on percentage of body weight of food digested per hour, in gar fed a single fish (0.8 gram) and those fed five fish (2.5 grams) was very noticeable. While the size of the meal increased slightly more than three times, the percentage of body weight of food digested per hour slightly more than doubled (2.2 times).

In order to obtain more information on this relationship, a meal of nine fish with a weight of 7.5 grams was force fed to each of three gar weighing 104, 106, and 120 grams, respectively. These fish were autopsied at the end of 50 hours, at which time the stomachs of two fish still contained 2 to 4 percent of the meal and one fish had an empty stomach but a filled intestine. The percentage of body weight of food digested per hour was 0.136. In this instance the size of the meal was again tripled while the amount of food digested per hour increased only 2.4 times. This relationship suggests that the rate of digestion is related to the amount of food present and that as the size of the meal is increased by a factor of three the amount of food digested per unit of time slightly more than doubles.

Warmouth

Forty-three warmouth were successfully carried through the force-feeding experiments. The fish ranged in total length from 153 to 179 millimeters, with an average of 165 millimeters. Weights ranged from 72 to 113 grams and averaged 93 grams. More than half of the fish weighed between 85 and 100 grams. The 2.5-gram meal fed to these fish constituted 2.21 to 3.47 percent of the individual body weight with an average value of 2.69.

Digestion proceeded much more rapidly in these fish than in the gar. Individual variation was considerable, although a plotted scattergram of the percentage of digestion values formed a rather compact linear arrangement of points. Percentage of digestion at various time intervals is shown in Table 2. A linear regression line was calculated which best fits the observed digestion rates (Figure 1). The regression value for the median of the selected time intervals is shown in the table. A measurable amount of digestion had occurred by the end of 3.5 hours and digestion was essentially completed in all fish between approximately 24 and 28 hours. Stomachs examined at the end of 28 hours and at subsequent times were all empty. The 100 percent regression value occurred at 26.2 hours. Digestion of 90 percent or more of the meal was observed as early as 21 hours, while one fish still contained 6 percent of the meal after 27 hours. Five of seven fish in the 25- to 27-hour interval were empty. Individuals varied in percentage of body weight of food digested per hour from 0.053 to 0.127, with an average rate of 0.093.

Largemouth bass

Bass of the proper size were difficult to obtain and only 18 individuals were successfully carried through the experiments. These fish varied from 190 to 225 millimeters in total length, with an average of 203 millimeters. Their weights varied from 71 to 115 grams with an average of 89 grams. Ten of the fish weighed between 85 and 100 grams.

The 2.5-gram meal represented 2.17 to 3.52 percent of the body weight with an average of 2.81. Digestion, when compared to that in the other species, was very rapid in these fish. Within 2 hours digestive erosion of the *Gambusia* had proceeded far enough so that some of them were completely skinned and the body cavity ruptured. Since digestion was very rapid, less variation in percentage of digestion at a given time occurred than in the warmouth or gar. Data concerning most of these fish are presented in Table 2. A calculated regression line indicated that the average bass would digest this size meal in 17.5 hours (Figure 1), although one fish still retained 10 percent of the meal after 18 hours. Observed individual variations in the time required for the stomach to empty ranged from 16 to 19 hours.

The percentage of body weight of food digested per hour varied from 0.110 to 0.216, with an average of 0.150. Digestion rates again showed no positive relationship to the weight of the bass. These rates of digestion are comparable to those reported by Markus (1932), who found that at 22° C. two largemouth bass weighing 175 and 177 grams digested a 5-gram minnow in 14 to 16 hours. Two smaller ones, 42 and 47 grams in weight, required 18 to 22 hours to digest a 4-gram minnow.

VOLUNTARY FEEDING

The few aquaria available limited the number of fish which were allowed to feed voluntarily. In these experiments the continuous period during which the fish were fed and

TABLE 2.—*Percentage of food digested by warmouth and largemouth bass at selected time intervals*

Hours after feeding	Warmouth				Largemouth bass			
	Number of fish	Percentage of food digested			Number of fish	Percentage of food digested		
		Range	Mean	Calculated regression average		Range	Mean	Calculated regression average
0 - 2	2	0	0	0	2	6 - 8	7	1
3 - 4	4	4 - 8	5	3	2	10 - 12	11	16
6 - 7	7	4 - 20	14	16	3	32 - 40	35	34
10 - 12	4	32 - 44	38	35	4	52 - 64	56	61
16 - 19	8	52 - 80	63	62	6	88 - 100	95	100
22 - 24	7	63 - 98	85	86				
26 - 27	6	94 - 100	99	100				

observed was as follows: gar, 22 to 34 days; warmouth, 18 to 20 days; bass, 11 to 15 days. Before measured feeding began, these fish had become thoroughly adjusted to aquarium life and the proximity of attendants.

Fish of all three species showed highly individualistic behavior. A few individuals would not feed actively while they were being closely watched. Others, particularly two of the bass, were very overt in feeding and would gorge themselves within 5 to 10 minutes. Fish of all species showed day-to-day fluctuations in the amount of food eaten. This behavior was particularly true of the gar which on occasion went as long as 48 hours without consuming food. Pearse (1924) reports that two longnose gar weighing about 40 grams were fed minnows for 26 and 30 days and consumed 1.82 and 0.60 percent of their body weight per day. These fish tended to be very irregular in their feeding habits.

Bass and warmouth, when hungry, would usually feed avidly whenever fresh food was offered. In contrast, the gar usually did not attempt to capture food fish even when hungry, if the room was brightly lighted. On numerous occasions the gar, which had been inactive for several hours, would begin to pursue the food fish when the illumination in the aquarium room was reduced to approximately that occurring at dusk.

The feeding activity of the gar consisted of a slow but continuous stalk, seemingly intended to place the anterior one-half of the snout parallel with and 2 to 3 inches from the intended prey, which would then be seized by a sidewise snap of the jaws. Once in proper position, the gar were surprisingly accurate in seizing a fish, which once impaled by the needle-like teeth never escaped. Because their feeding movements were deliberate, the gar required a considerable amount of time to secure an average meal. Success in capturing a fish in a given period of time seemed to be related somewhat to the number of food fish present and to the illumination.

Observation and autopsy showed that bass and warmouth voluntarily ate newly-offered food although considerable food from a previous meal still remained in the stomach. Whether gar behaved similarly was not determined with certainty because of the slowness with which they fed. Comparison of the known rate of digestion and the daily food intake suggested that in most instances the gar after one meal did not feed again until the stomach was empty or nearly so.

A summary of the results of the voluntary feeding is given in Table 3. Although considerable variation in the food intake of individual fish of each species is apparent, the difference between the three species is very marked. The bass consumed the most food, the warmouth somewhat less, and the gar comparatively little. The average percentage of body weight of food consumed per 24 hours was 7.01, 4.37, and 2.81 for the three species respectively. Compared to the bass, the warmouth consumed 62 percent as much food while the daily intake of the gar was only 40 percent.

TABLE 3.—*Voluntary food consumption in gar, warmouth, and largemouth bass*

Species	Specimen number	Weight in grams	Percentage of body weight consumed			Days to consume body weight of food
			1 hour	24 hours	Greatest amount in 24 hours	
Gar	1	100	0.097	2.35	5.60	43
	2	84	0.102	2.44	5.42	35
	3	113	0.108	2.59	5.39	39
	4	120	0.124	2.97	8.33	34
	5	106	0.154	3.71	8.49	27
	Average	105	0.117	2.81	6.64	36
Warmouth	1	115	0.144	3.46	4.69	30
	2	82	0.219	5.26	10.48	19
	3	100	0.183	4.39	8.20	23
	Average	99	0.182	4.37	7.79	24
Bass	1	118	0.352	8.44	12.3	12
	2	90	0.291	6.98	12.0	14
	3	96	0.232	5.57	10.8	18
	Average	101	0.292	7.01	11.7	15

It has been stated that very young fish eat proportionately more food than older individuals of the same species (Pearse, 1924; Hathaway, 1927). Two small gar, 30 and 35 grams in weight, were fed for 20 days during which the average daily food consumption was 4.26 percent of their body weight. This rate is nearly equal to that of the adult warmouth and is approximately 66 percent greater than that shown by gar weighing about 100 grams.

CONCLUSIONS

Comparison of these three species shows that the digestion rate of the warmouth is 1.6 times greater than that of the gar, and that of the bass is 1.5 times greater than that of the warmouth and 2.4 times greater than that of the gar. Similarly the voluntary daily food consumption of the warmouth was 1.6 times greater than the gar, and that of the bass 1.6 times that of the warmouth and 2.5 times that of the gar.

These differences correspond with observed differences in activity. The bass were usually moving about continuously while the warmouth were much less active. The gar were slow in their movements and tended to be very sedentary. Relative inactivity of the gar appears to be associated with irregular feeding habits, low food consumption, and slow rate of digestion.

Disregarding the fact that the warmouth were adults, while the gar and bass were young, immature fish, the data show very clearly the different quantitative food needs of the three species. It is apparent that if these rates of food consumption are applicable to the natural populations of these fishes, the amount of food required to support one bass is sufficient to support two and one-half gar. Judged on the basis of food needs, the gar would seem to be much more efficient than either the bass or the warmouth.

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Recovery, Growth, and Movement of Hatchery-Reared Lake Atlantic Salmon at Long Pond, Maine[1]

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ABSTRACT

Three groups of fin-clipped, hatchery-reared salmon, *Salmo salar*, stocked at Long Pond, Hancock County, Maine, between 1952 and 1954 yielded an estimated 4.0 percent return to anglers during the 4 years (1955-1958) following the final stocking. The individual groups of approximately 3,000 fall-stocked salmon (age-group I+) were recovered at rates of 5.0, 0.76, and 6.1 percent. Hatchery-reared salmon comprised over 90 percent of the total salmon catch during the census period. Creel-census methods are described. Open-water fishermen caught hatchery-reared salmon at a rate of 0.060 fish per line hour from 1955 to 1957 inclusive. Ice fishermen took 0.0047 salmon per line hour during the same years. From 1954 to 1958 ice fishermen expended 58.0 percent of the total fishing effort and took 14.8 percent of the salmon catch. Survival, growth, and exploitation rates of the different groups of salmon are compared and discussed. Forty-six of the 9,271 salmon stocked moved down the outlet of Long Pond in the 6-year period following the first stocking. Only one of these salmon continued on to sea. Management implications arising from the study are discussed.

INTRODUCTION

Lake Atlantic or landlocked salmon, *Salmo salar*, have been stocked in Maine lakes for many years, but little quantitative information has been obtained concerning their recovery by anglers, survival rates, growth rates, and movements within the waters stocked. From 1952 through 1954, fin-clipped, hatchery-reared salmon were stocked annually at Long Pond, Hancock County. From 1954 through 1958, ice- and open-water-fishing creel censuses were operated to assess recovery and survival of these salmon and to obtain scale samples for growth studies. The censuses were conducted from the time the group of salmon stocked first entered the fishery until the group stocked last almost disappeared from the fishery.

Movements of these salmon within and from the Long Pond drainage were studied from 1952 through 1958 by operation of two-way fish traps in the outlet of the pond. The traps were in service when the first group of salmon was stocked and were operated from early spring through late fall during the project period.

DESCRIPTION OF LONG POND

Long Pond has an area of 897 acres and lies at an elevation of 59 feet above sea level. Maximum and average depths are 120 and 39 feet, respectively. Surface temperatures rarely exceed 72° F., and hypolimnion temperatures usually range between 47° F. and 50° F. Dissolved oxygen exceeds 7 p.p.m. at all depths. The water is uncolored and slightly acid. The pond satisfies the requirements for oligotrophy.

Salmon were first introduced into Long Pond about 1895 and smallmouth bass, *Micropterus dolomieui*, about 1940. Brook trout, *Salvelinus fontinalis*, are natives of the drainage. Other species present include chain pickerel, *Esox niger;* alewife, *Alosa pseudoharengus*, (anadromous) ; American smelt, *Osmerus mordax;* white sucker, *Catostomus commersoni;* golden shiner, *Notemigonus crysoleucas;* northern redbelly dace, *Chrosomus eos;* and American eel, *Anguilla rostrata.*

Of the 11 tributaries to Long Pond, seven are of no value as spawning and nursery area for salmonids; three provide limited amounts of trout spawning and nursery area; and one, Great Brook, provides a small amount of spawning and nursery area suitable for salmon. The outlet of Long Pond is approximately 1½ miles long and enters the sea at Somes Sound. There are four dams, 3 to 6 feet high and provided with fishways, in the outlet. The uppermost serves as a water regulatory structure for Long Pond. The next dam downstream holds a 3-foot head on Somes Pond (104 acres) for æsthetic purposes. The

[1]This project was partly financed and administered by Dingell-Johnson Act funds as Project F-2-R, Maine.

two lowermost dams impound small ponds (less than 1 acre) for fire prevention in the village of Somesville.

Long Pond is considered to be representative of at least 10 lakes currently managed for salmon in northeastern Maine. These lakes are characterized by good water quality; the presence of a population of smelts, the major forage fish of salmon; the presence of one or more competing warm- and cold-water game species; and a shortage of salmon-spawning and nursery area.

EXPERIMENTAL PROCEDURES

Stocking

A summary of the three salmon stockings made at Long Pond between 1952 and 1954 is given in Table 1. All salmon were from age-group 1+ when stocked and were planted at three widely separated locations in Long Pond. Approximately one-half of the 1952 and 1953 groups were distributed in or near the mouth of Great Brook. The 1952 stocking was the first in Long Pond since the summer of 1948 when 15,000 advanced salmon fry were planted. It is unlikely that these fish influenced the experimental stockings made over 4 years later. All fish were anesthetized with urethane (17 grams per gallon of water) to facilitate fin clipping. They were held at the hatchery for 1 to 3 days before stocking and no post-clipping mortality was noted.

TABLE 1.—*Summary of landlocked salmon stocked in Long Pond, Hancock County, Maine, from 1952 to 1954*

Year	Month stocked	Number stocked	Pounds stocked	Total length in inches	Mark
1952	October	3,000	468	7.5 ± 0.10	Left and right pelvic
1953	September	3,005	188	5.7 ± 0.04	Adipose and left pelvic
1954	October	3,266	153	4.9 ± 0.05	Adipose and right pelvic

Creel-census methods

During 1954 complete ice- and open-water-fishing creel censuses were operated at Long Pond. From 1955 through 1958 annual catches of salmon were estimated from sample catches per unit of effort and estimates of total effort. Ice-fishing censuses were operated daily in 1955, on weekends in 1956, and on 4 to 6 randomly chosen days a week in 1957 and 1958. Open-water censuses were operated on weekends and 2 randomly chosen weekdays in 1955, on weekends and 1 randomly chosen weekday in 1956, and on 4 to 6 randomly chosen days a week in 1957 and 1958. All censuses were of the personal-interview type and on a day-long basis. Ice fishermen were contacted at fishing sites, and open-water fishermen were checked at the pond's two public boat landings. An estimated 85 to 90 percent of total fishing effort expended on census days was recorded. No expansions of effort that consider incompleteness of the check on census days have been made.

Estimates of open-water fishing effort. — The 1957 and 1958 censuses were operated for enough days to provide estimates of average daily fishing effort which would not differ from the true average daily effort by more than 3 line hours. The necessary number of days was determined from the following formula:[2]

$$n = \frac{\left(\frac{2s}{d}\right)^2}{1 + \frac{1}{N}\left(\frac{2s}{d}\right)^2}$$

The required number of census days is n, d is the error tolerance at the 95 percent confidence level (3 hours in this study), N is the total number of fishing days in the season, and s is the standard deviation of average daily efforts (total of hours fished) in a sample census period. The standard deviation of the sample census period used was computed from the daily 1954 census.

Total efforts for the 1957 and 1958 seasons were computed by multiplying total numbers of fishing days in the seasons by the average daily efforts so calculated. Ranges in total effort were computed by multiplying total numbers of fishing days in the seasons by the 95 percent confidence limits of the average daily efforts.

Error tolerances for average daily effort during weekdays for the 1955 and 1956 censuses were not designated beforehand as they were for the 1957 and 1958 censuses, but were calculated at the completion of these censuses. Appropriate weekday values for n, N, and s, the latter based on the 1954 weekday sample, were substituted in the formula which was then solved for d, the error tolerance. The

[2]Statistical procedure suggested by Dr. Douglas Robson, Biometrics Unit, Cornell University, Ithaca, New York.

hour values obtained were then subtracted from and added to the mean daily weekday efforts to obtain confidence limits for mean daily weekday efforts. Total weekday efforts with their confidence limits were then calculated and added to recorded weekend efforts to obtain total seasonal efforts.

Estimates of ice-fishing effort. — Confidence limits for 1957 and 1958 ice-fishing effort were calculated in the same manner as those for 1957 and 1958 open-water fishing; however, the error tolerance was set at 10 hours. The 1956 ice-fishing census was operated only on weekends. During the winter fishing seasons of 1954, 1955, and 1957, approximately 70 percent of the fishing effort was expended on weekends. Recorded weekend effort for 1956 was estimated to be 70.0 percent of the total effort expended.

Estimates of total catch. — Estimates of total catch for sampled census periods were derived from estimates of ranges in total effort and sample catches per unit of effort. For any sampled fishing season, total estimated effort and each of its confidence limits were multiplied by the sample catches per unit of effort. The products were the estimated total catches and ranges in total catches.

Age and growth analysis

Scale samples for age and growth analysis were secured from hatchery-reared salmon throughout the project period. Scales were taken from the left side of the fish between the lateral line and origin of the dorsal fin. Readings and measurements were made with a scale projector which provided magnification of 45 diameters.

Total lengths at previous ages were calculated by the proportional formula:

$$L' = C + \frac{S'}{S}(L - C),$$

where L' = calculated total length, S' = scale length from focus to individual annulus, L = total fish length at time of capture, S = scale length from focus to anterior margin, and C = correction factor (1.0 inch). The correction factor was obtained by plotting scale lengths (anterior scale radii) against the total lengths of 211 Long Pond salmon and extrapolating the fitted straight regression line to the total length (X) axis.

Trapping of fish

Two fish traps, located in fishways and designed to catch fish moving in either direction, were operated in the outlet of Long Pond during most of the study period. Except for mid-winter months, a trap was operated at the junction of the lake and the outlet (upper trap) from 1952 to 1958. Beginning in October 1953 another trap was operated at the head-of-tide junction of the outlet and Somes Sound (lower trap).

Within the trapping periods the upper trap was operated almost continuously. Occasionally spring high water necessitated suspension of trapping for 1 to 3 days, but no major fish movement went undetected. The lower trap was not operated during a 2- to 4-week period in June and early July when spent alewives were migrating from the drainage in large numbers. Traps were checked almost daily and data on the fish were recorded. Spillways at the dams were screened to prevent undetected downstream migrations.

RECOVERY OF HATCHERY-REARED SALMON

Annual recoveries by anglers of salmon stocked at Long Pond from 1952 to 1954 are given in Table 2. The total estimated catch of 375 salmon through 1958 represents a recovery of 4.0 percent of the 9,271 fish stocked, the percentage returns being 5.0, 0.76, and

TABLE 2.—*Estimated return of salmon stocked in Long Pond to the sport fisheries during 1954-1958*

[The numbers in parentheses are 95 percent confidence limits as in text]

Year stocked	Number stocked	Year					Number returned	Percentage return
		1954	1955	1956	1957	1958		
1952	3,000	2	54 (42-65)	36 (23-49)	53 (46-60)	5 (4-6)	150 (117-182)	5.0 (3.9-6.0)
1953	3,005	0	3 (2-4)	4 (2-6)	13 (11-15	3 (2-4)	23 (17-29)	0.76 (0.56-0.96)
1954	3,266	0	0	94 (28-158)	90 (80-101)	18 (13-23)	202 (121-282)	6.1 (3.7-8.6)
Total	9,271	2	57	134	156	26	375 (255-493)	4.0 (2.7-5.3)

6.1 for the year groups 1952, 1953, and 1954, respectively. On the basis of weight at time of stocking, estimated returns for the 1952, 1953, and 1954 groups were approximately 43, 24, and 284 percent, respectively. During the years 1955-1958 hatchery-reared salmon comprised from 87.1 to 98.2 percent of the annual recorded catches.

The relatively low recovery (0.76 percent) of salmon stocked in 1953 (Table 2) suggests that this group suffered a large, post-stocking mortality. Burdick and Cooper (1956), who worked with fingerling rainbow trout, *Salmo gairdneri*, showed that survival in Weber Lake, Wisconsin, was low when survival of the previous year's planting was high. Competition between the 1952 and 1953 groups may have been the major cause for the indicated mortality of the 1953 group. Salmon stocked in 1952 survived in large numbers. Fishermen reported releasing about 500 and 300 sublegal fish (less than 14 inches) of this group during 1954 and 1955, respectively.

Substantially better recovery of hatchery-reared salmon would probably have been obtained if fishing effort had been greater. During the 5-year census period, open-water fishing effort varied from 1,254 hours (1956) to 3,614 hours (1957). For all years except 1957, open-water effort was less than 3,000 line hours. Ice-fishing effort varied between 1,213 hours in 1958 and 11,974 hours in 1957, but the effort was usually less than 2,000 hours.

Fishing effort at Long Pond may seem small, but on an acre basis these efforts are quite typical for accessible salmon lakes in northeastern Maine. Open-water fishing effort at Long Pond approximates 2.6 line hours per acre per year. Effort per acre for two summer censuses at Cold Stream Pond in Penobscot County was also 2.6 line hours per year based on nearly complete censuses (Bond and DeRoche).[3]

GROWTH OF HATCHERY-REARED SALMON

Calculated growth of salmon stocked at Long Pond in 1952 and 1954 is compared in Table 3. Fish of the 1952 group grew significantly slower than salmon of the 1954 group throughout their entire life. Their sizes at age-group III were similar, but the 1952 group slowed markedly in growth beyond that age. Possible reasons for this variation in growth rates include fluctuations in the smelt population, genetic differences, racking or sorting, and intra-specific competition. The major food of salmon beyond age-group III at Long Pond is smelts. Possibly the smelt population was low during 1954 and 1955, the years when smelts should have become the major food of the 1952 group. If this hypothesis is correct, the smelt population must have recovered by 1956, because the 1954 group demonstrated excellent growth during that year. Growth increments of the fish planted in 1952 for the years 1955 (1.3 inches) and 1956 (2.1 inches) indicate that the growth of this group increased during 1956.

TABLE 3.—*Calculated total lengths of salmon stocked in 1952 and 1954 at Long Pond*[1]*—expressed in inches*

Stocking	Age group					
	I	II	III	IV	V	VI
1952	3.7	8.0	11.4	13.4	14.7	16.8
1954	3.0	5.4	11.7	16.6	19.5	24.0

[1]Most growth calculations derived from angled fish and based on more than 30 observations.

The 1952 group were progeny of salmon from Sebago Lake in southern Maine, and the 1954 group were progeny of salmon from Grand Lake in northeastern Maine. Genetic differences that influence growth rates may exist between the two groups. The salmon stocked in 1952 were "racked" to obtain large individuals for stocking. The 1953 and 1954 groups were selected at random. Salmon that grow rapidly when young, may grow slowly as older fish.

When the 1952 group was stocked, Long Pond was almost devoid of salmon. Probably not more than 20 salmon were caught in 1952 and 1953, and the total recorded catch for 1954 was 17 fish. Fish of the 1952 group may have survived the initial stocking and reached a fish-eating size in such large numbers that they created a critical food shortage. It has already been pointed out that at least 800 sublegal salmon of this group were caught by anglers in 1954 and 1955. By 1956 normal natural mortality could have progressed to a point where the smelt population recovered sufficiently to permit normal growth of the salmon stocked in 1954, especially if survival

[3]Bond, Lyndon H., and Stuart E. DeRoche. (1956) Landlocked salmon and brook trout of the Cold Stream Drainage, Penobscot County, Maine. D-J Final Report, Project F-5-R. Mimeographed, 23 pp.

of this group was somewhat repressed by the 1952 group.

FISHING QUALITY OF HATCHERY-REARED SALMON

Line-hour catches per unit of effort for hatchery-reared salmon for the years 1955, 1956, 1957, and 1958 (open-water fishing) were 0.025, 0.101, 0.032, and 0.008, respectively. Ice-fishing catches per unit of effort for corresponding years were 0.0031, 0.0044, 0.0046, and 0.0016. During the 4-year period 1955-1958, ice fishermen expended 58.0 percent of the total fishing effort (line hours) and took 14.8 percent of the total salmon catch.

From 1955 to 1957, when hatchery-reared salmon were available in relatively large numbers at Long Pond, open-water anglers took them at a rate of 0.060 salmon per line hour (293 fish in 4,852 line hours). During two summer censuses at Cold Stream Pond in 1952 and 1953, Bond and DeRoche *(op. cit.)* recorded a salmon catch of 465 fish in 19,026 line hours for a catch per line hour of 0.024. Warner[4] recorded a catch of 749 salmon in 12,758 line hours during a census of five of the Fish River Lakes in 1957 for a catch per line hour of 0.058 salmon. In calculating the figure 0.060 for Long Pond, effort in line hours by bass fishermen for bass only was excluded from total effort in line hours expended. Bass fishermen rarely take salmon at Long Pond. Effort in line hours at the other lakes is effort for all cold-water game species.

Catch per unit of effort for hatchery-reared salmon at Long Pond compares favorably with catches per unit of effort for salmon at other Maine lakes. Salmon at Cold Stream Pond are both hatchery and naturally-reared fish. Salmon in the Fish River Lakes are mostly naturally-reared.

SURVIVAL OF HATCHERY-REARED SALMON

Catches per unit of effort by open-water fishing for salmon stocked in 1952 were 0.041, 0.037, 0.013, and 0.0017 for 1955, 1956, 1957, and 1958, respectively (age-groups IV-VII). Catches per unit of effort for the 1954 group (age-groups III-V) for 1956, 1957, and 1958 were 0.117, 0.020, and 0.0056, respectively. Survival rates computed from these successive catches per unit of effort (Ricker, 1958) were as follows:

Age	Survival rate	
	1952 group	1954 group
III-IV	—	0.170
IV-V	—	0.280
V-VI	0.351	—
VI-VII	0.130	—

Survival rates for salmon of the 1952 group younger than age-group V were not computed because this group did not become fully vulnerable to the sport fishery until they reached that age in 1956. Survival rates computed from angler catches per unit of effort may be too low for older fish if they become increasingly more difficult to catch with increased age.

The rapid decrease in fishing quality for the 1954 group and the gradual decrease in fishing quality for the 1952 group reflects the different manner in which these two populations were exploited. Almost the entire catch of the 1954 group occurred during the fall of 1956 and the spring of 1957. This abrupt exploitation of the 1954 group is also reflected in the relatively low survival rate of the group (0.170) from age-group III to IV. In contrast, exploitation of the slow-growing 1952 group was spread out over a full 3-year period.

The decreasing survival rate with age of the 1952 group is to be expected. At age-group VI salmon are nearing the end of their normal life span. The increased survival rate between age-groups IV and V for the 1954 group is probably real. Since this group was exploited at an early age, and the survivors grew to a large size at age-group V (5 to 8 pounds), they were undoubtedly more difficult for anglers to catch.

MOVEMENTS OF STOCKED FISH

Sportsmen often contend that many salmon leave the lakes in which they are stocked by swimming down the outlet. Expensive fish screens have been constructed at outlets of many lakes to prevent these reported emigrations. During the 6-year trapping study at Long Pond, only one hatchery-reared salmon was trapped while leaving the outlet stream to enter the sea. This fish was an adult of the 1952 stocking and was taken in 1955 at the

[4]Warner, Kendall. (1958) An investigation of Landlocked Salmon in the Fish River Chain of Lakes. Job Completion Report, Investigation Projects, Project F-11-R-3, Job IV. Mimeographed, 7 pp.

lowermost trap in Long Pond Outlet. It is not believed that the fishway traps which were used disturbed fish movement in any way. During the trapping many thousands of migrating young and adult alewives were captured.

Movement downstream through the trap at the pond-outlet junction consisted of 20 juvenile and 26 adult salmon. Upstream movement of hatchery-reared salmon at this trap consisted of 8 juvenile and 13 adult fish. Movements of juvenile salmon occurred soon after stocking. Adults were captured during fall spawning migrations.

The significance of this phase of the Long Pond salmon study lies in the fact that less than 50 of over 9,000 salmon stocked in Long Pond over a 3-year period moved down the outlet during a 6-year period following the first stocking. The evidence obtained clearly points out that the installation of fish screens in outlets of lakes of this type to prevent loss of stocked salmon is unnecessary. Warner (1959) has shown that even where large downstream spawning emigrations occur, most of the fish return to home waters after spawning.

MANAGEMENT IMPLICATIONS

Results indicate that a planting program to maintain fisheries for landlocked salmon in Maine lakes lacking habitat for natural reproduction is a desirable management technique. The catch per unit of effort provided by hatchery-reared salmon at Long Pond compares favorably with catches per unit of effort at well-known salmon lakes for which information is available. On a catch-per-acre basis the yields provided by hatchery fish at Long Pond are probably not markedly different from catches at the larger well-known salmon waters.

The landlocked salmon, because it has limited distribution in North America, has extremely high sporting value. Numerous small fisheries which are well-dispersed geographically will provide more angling opportunities and fishing recreation for this species than fisheries concentrated in a few large but widely separated waters.

The variation in growth and survival rates of the different groups of salmon stocked at Long Pond demonstrates that major differences in vital statistics of salmon populations of hatchery origin may be expected even within small, uniform habitats. Of particular interest are the initial high survival but subsequent poor growth rate of the group stocked at a low existing population density (1952 group) and the apparent large mortality of the group stocked at a high existing population density (1953 group). The experiments are currently being repeated at Long Pond using approximately 6,000 rather than 3,000 salmon, but additional studies of this nature should be conducted on other salmon waters.

The failure of salmon stocked at Long Pond to utilize the outlet stream as a spawning area in significant numbers leads to the hypothesis that landlocked salmon return to home streams even within small drainages. Limited observations at Great Brook, the major inlet, during 1955 indicated that some hatchery-reared fish of the 1952 group were using this stream as a spawning area. Part of the 1952 group were stocked at the mouth of this stream. Beaver dams that completely inundated the lower reaches of Great Brook were constructed in 1956, so further observations were impossible.

In 1958, 1,000 fin-clipped salmon were stocked in the outlet of Long Pond. Equal numbers will be stocked annually through 1963. If outlet trapping demonstrates the development of a spawning run of these fish to the outlet, stocking plans for salmon lakes should include some stocking of suitable inlets or outlets where runs are not already established.

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Swimming Performance of Juvenile Sockeye Salmon in Salt and Fresh Water

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ABSTRACT

An experiment was conducted to explore the hypothesis that the swimming performance of salmonoids in sea water is higher than that of similar fish in fresh water. Young sockeye salmon *(Oncorhynchus nerka)* swam longer in salt water. Duration of swimming increased with size of fish.

INTRODUCTION

Most information on salmonoid swimming performance comes from observations in fresh water relating to fish passage problems. Marine swimming performance studies have not received the same attention. Performance capacities in sea water are of interest as some estuarine hydraulic structures and impoundments may form sharp transitions between the marine and fresh-water environments, requiring migrating salmonoids to negotiate varying flows of saline or fresh water. Information on the relative swimming abilities in these different media would assist in interpreting the effects of such structures upon migrants. An indication that salmonoid swimming performances in sea water are different from performances in fresh water is suggested by the results of muscular fatigue experiments in which marine and fresh-water salmonoids were similarly exercised but the marine fish often did not recover.

In experiments assessing the effects of capture and handling upon salmon, Parker and Black (1959) caught marine chinook salmon (*Oncorhynchus tshawytscha*) and exercised them at sea on troll lines. They reported high mortalities following severe sustained 15-minute exercise. These studies were extended the following year to include marine coho salmon (*O. kisutch*) which were caught and similarly exercised at sea on troll lines (Parker *et al.*, 1959). Again mortalities followed as in the chinook experiments. However, when fresh-water-captured coho were subjected to the same exercise on troll lines in fresh water, no mortalities resulted.

In another muscular fatigue study Black (1957c) noted deaths occurring in 2-year-old hatchery reared sockeye salmon (*O. nerka*) which had been severely exercised for 15-minute periods in troughs of sea water. These fish had been exposed to salt water for 1½ years. Again, results contrasted with the results of similar controlled experiments in fresh water of Kamloops trout (*Salmo gairdneri*) (Black, 1955, 1957a) and lake trout (*Salvelinus namaycush*) (1957b) in which no mortalities were caused by exercise.

The relationship between extreme performance, or exercise, and death in fish has been reviewed by Black (1958). This mortality is generally attributed to a large increase in blood lactic acid released by the rapid breakdown of muscle glycogen, an energy reserve for severe muscular effort.

In the experiments cited, death following the severe exercise was correlated with significantly higher levels of lactic acid. These higher levels of lactate and the mortalities which seemed associated with the fish in a marine environment may indicate that in sea water the actual amplitude of muscular activity is greater for a given exercise period — that the salmonoid in sea water makes a greater effort than its counterpart in fresh water.

The purpose of the experiment described in this report was to examine the hypothesis that salmonoid swimming performance is higher in sea water than in fresh water by comparing, under controlled conditions, the duration of peak or "burst" swimming performances of young salmon in both media.

MATERIALS AND METHODS

The experiment was conducted at the Fish Behavior Laboratory of the Seattle Biological

Laboratory, Bureau of Commercial Fisheries, Seattle, Washington. The available fish were 1-year-old sockeye salmon (*Oncorhynchus nerka*) from the Federal Hatchery at Winthrop, Washington. Their average weight was 7 grams.

Apparatus

A swimming channel was formed by connecting two water-tight boxes with a 48- by 4- by 3-inch trough which was screened at each end (Figure 1). A continuous stream was circulated through the channel by pumping salt or fresh water from one box to the other. A second pump accelerated the water velocity in the channel so that high performances, which were brief but conveniently measurable, were forced from the fish. Preliminary trials indicated that a velocity of 2 feet per second, measured with a current meter, required the fish to swim hard to maintain a positive position in the stream. This water velocity was used in the tests.

The fish were stimulated to swim against the flow by a small electric current between two electrodes placed in the water at the lower end of the trough. The applied voltage was low so that the current was just sufficient to cause avoidance. If a fish was held between the electrodes it appeared unaffected even after several minutes. To allow for differences in conductivity between salt and fresh water the voltages were regulated with a variable transformer. At the best evident response levels, the voltages were measured with a vacuum tube voltmeter. Ten volts across 3-inch electrode spacing gave the best stimulus in fresh water and 1.5 volts in salt water.

The temperature of the recirculating water was precisely held at the fish's environmental level by regulating coils which were immersed in the boxes.

The sea water used in the tests and for acclimation and holding was transported from Puget Sound and stored at the Seattle Laboratory. The fresh water was from the domestic supply.

Design

The general plan was to acclimatize 150 fish to salt water for 1 week, individually measure their swimming performances in the test channel, and compare them with a similar control group of 150 held in fresh water. The fish were acclimated in outdoor covered circular steel tanks 4 feet in diameter. Two hundred fish were placed in each tank to assure an adequate sample. Mortalities were replaced and at the time of testing the fish had been exposed to salt water for 1 week. Water was maintained in a closed system and aerated by recirculating pumps. The temperature was not regulated, but during this period the water temperature varied only be-

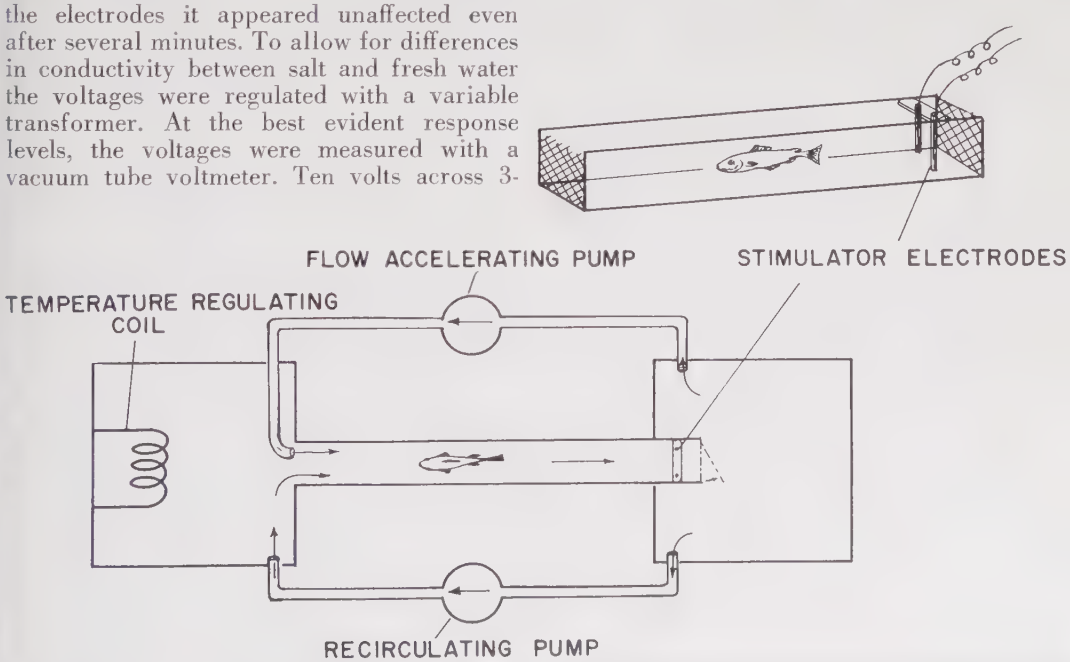

FIGURE 1.—Diagram of an exercise channel used to compare the swimming performances of yearling sockeye salmon in salt and fresh water.

tween 9° C. and 11° C. The fish were not fed during the experiment since individual variations in food consumption might have influenced performance capacities apart from the experimental variables. Tests were planned to cover a 2-day period so that each group of salt- and fresh-water fish was tested both morning and afternoon as follows:

Time	Day 1	Day 2
Morning	75 fish (fresh-water)	75 fish (salt-water)
Afternoon	75 fish (salt-water)	75 fish (fresh-water)

Procedure

The temperature of the test water was adjusted to the level of the outdoor acclimation tanks, and the velocity pattern was established in the channel. The electrodes were energized and a fish introduced into the trough to head into the stream flow.

When each fish could no longer hold its position away from the electrodes the swimming time was recorded and it was removed and weighed to the nearest gram. In this way swimming performance of fish of the same size could be compared in the different media.

RESULTS

The total mean swimming times of the two groups are compared in Table 1. The salt-water fish swam 43 percent longer in the test channel. However, the mortalities which occurred during acclimation removed mostly smaller fish from the salt-water group, so that the average weight of this group was 25 percent greater than the fresh-water average. This probably contributed to the overall increased salt-water performance, since it could be expected that larger fish generally would have correspondingly larger capacities to work against a constant water current.

DISCUSSION AND CONCLUSIONS

By recording individual weights and performances, the effect of fish size was evaluated in this test. This is illustrated in Figure 2, in which swimming time in the channel is plotted against fish weight. Each point represents the average swimming time of all fish of that particular weight in each test medium. Regression lines were calculated from these points.

A proportional size-performance relationship shows in each test group. The correlation appears closer with the salt-water ac-

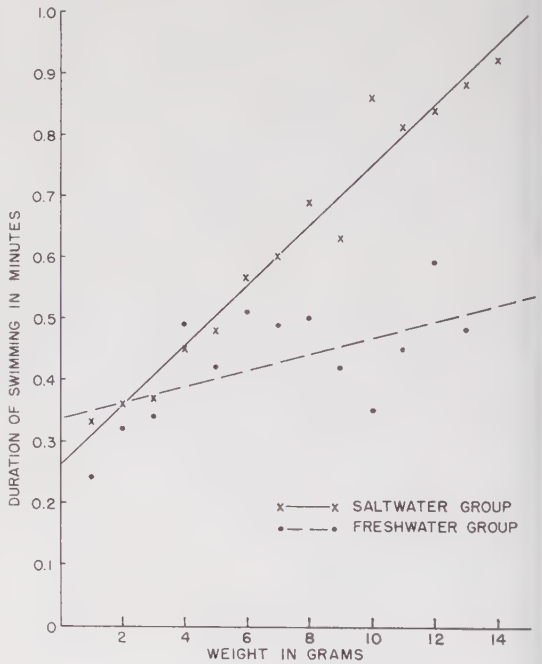

FIGURE 2.—The swimming performance and size relationship of two groups of exercised yearling sockeye salmon. One group was acclimated and exercised in salt water. The second group was exercised in fresh water.

TABLE 1.—*Summary of swimming performances of 1-year-old sockeye salmon in fresh water and salt water*

Test medium and time	Number of fish	Total weight (grams)	Average weight per fish (grams)	Total time of group (minutes)	Mean time (minutes)
Fresh water					
Morning	75	436	5.8	34.44	0.46
Afternoon	75	519	6.9	31.58	0.42
Total group	150	955	6.3	66.02	0.44
Salt water					
Morning	75	526	7.0	44.56	0.59
Afternoon	75	666	8.9	49.21	0.66
Total group	150	1,192	7.9	93.77	0.63

climated fish. Brett, Hollands, and Alderdice (1958) reported a similar effect of size on swimming performance with juvenile sockeye and coho salmon.

The fish swam for longer periods in salt water. The increased performance agrees with observations of Black (1957c) who noted that exercised sea-water acclimated yearling sockeye were more active than similar fish in fresh water.

Since these results were from tests with acclimated juvenile fish, only speculative extrapolations can be extended to salmonoids in their marine environment. However, no disagreement seems evident if the exercise experiments of Black (1957c) and Parker and Black (1959) are reconsidered with these results. The indications are that a salmonoid probably performs at a higher level in salt water than in fresh water.

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First-Year Growth of the Largemouth Bass, *Micropterus salmoides* (Lacépède), and Some Related Ecological Factors[1]

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ABSTRACT

First-year growth of largemouth bass taken from Lake George and adjoining slough, Anoka County, Minnesota, during a 4-year period was described. Illumination, water chemistry, abundance of bass fingerlings, yearlings, and other fish did not influence growth rate or total season's growth. Total length at end of season varied from 56 to 85 millimeters and was contingent upon length attained on August 1, which was directly related to total temperature experience to that date. Rates of embryo development, sac-fry growth, and fingerling growth during the first 4 weeks and again at the end of the season were directly related to the mean daily water temperature. Growth rate during the first 2 weeks after rising was directly related to amount of food in stomachs, and near the end of the season to the ratio of large organisms to small organisms. Differences in relative condition factor *(Kn)* between areas in a single year were directly related to stomach weight, while differences in condition among years within an area were inversely related to abundance of bass fingerlings. No differences in growth between sexes were found.

INTRODUCTION

The total growth of scaled fish during their first year of life is usually estimated from selected scales of older fish on which length at first annulus has been calculated. Such rate-of-growth studies on the largemouth bass, *Micropterus salmoides* (Lacépède), demonstrate that there is considerable variation in length at first-annulus formation among individuals, among year classes, and between fish from different areas (Bennett, 1937; Stroud, 1948; Padfield, 1951). In some cases there was so much variation that it was impossible to distinguish between I- and II-annulus bass on the basis of length alone. Most age and growth studies only describe these variations since collections are made on few occasions and possible influencing environmental factors are not measured. The influence of some of these factors on growth has been demonstrated, but definite relationships have not been established for others.

It has been shown in both marine and freshwater fisheries that the catch is influenced by year-class strength, and it has been generally assumed that the numerical strength of individual year classes is determined during the first growing season. If this assumption is valid for the largemouth bass, rate of growth during the first growing season may affect the survival rate and hence the availability of fish for the angler. The objectives of the present study were to describe first-year growth and determine the influence of various environmental factors which may affect it. This work was part of a more comprehensive program on year-class formation in largemouth bass conducted by the University of Minnesota in cooperation with the Minnesota Department of Conservation (Dingell-Johnson Project F-12-R). Donald R. Franklin and Evelyn B. Kramer assisted in field operations.

Study areas

All field observations were made at Lake George, Anoka County, Minnesota (Figure 1) and at one of two adjacent sloughs used by bass for spawning purposes so that the growth of bass fingerlings in two different habitats, but from the same assumed gene pool, could be compared.

Lake George.—Lake George lies in an ice-block basin of a glacial outwash plain (Zumberge, 1952). It has a surface area of 535 acres, is roughly circular in shape, and has a maximum depth of 32 feet. The shoreline is hard sand which extends out to a depth of

[1]Paper No. 4332 Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul 1, Minnesota.

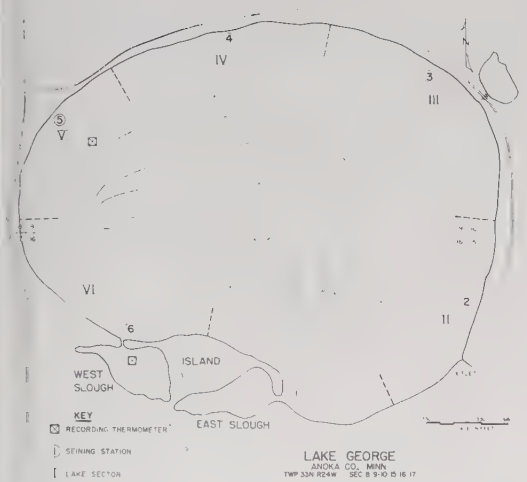

FIGURE 1.—Lake George, Anoka County, Minnesota.

about 6 feet, except in a limited area where sand is mixed with gravel and stone. There are no permanent inlets, but in spring and early summer there is drainage from marshes and lowlands. A concrete drop-culvert in an outlet ditch controls the level of Lake George and permits excess water to flow into the Rum River, a tributary of the Mississippi River. The lake is moderately hard with a total alkalinity which varies from 81-110 p.p.m. in May to 78-88 p.p.m. in July. The lake water is moderately fertile with a phosphorus content of 0.025-0.030 p.p.m. and a total nitrogen content of 1.03-1.28 p.p.m. Lake George is a typical warm-water fish lake of central Minnesota with a total of 30 species making up the population. The predominant game species are largemouth bass, northern pike *(Esox lucius)*, and sunfish *(Lepomis* spp.).

West Slough.—Behind an island on the south side of the lake there are two small sloughs, separated from each other but connected to the lake by narrow channels. They have soft bottoms of silt and organic debris except on their lakeward margins where there are limited sand areas. They were dry and under cultivation during the 1930's, but during the study period had maximum depths of 4.5 feet. Both sloughs were utilized by largemouth bass for spawning and nursery areas. Since the sloughs were similar, the West Slough only was used for intensive study and the East Slough for supplementary observation. The West Slough has an area of 9.2 acres, and its water level fluctuates with that of the lake. Aquatic plants are abundant and there is an almost unbroken coverage of white water lily *(Nymphaea tuberosa)* during midsummer. The total alkalinity varied from a high of 63-106 p.p.m. in May to a low of 46-58 p.p.m. in July. During the winter, when there was an absence of dissolved oxygen, the total alkalinity was 160-189 p.p.m. Numbers of dead sunfish found each spring indicated that there was no survival of game fish during the winter. In the summers there was no evidence of fish kills from overnight oxygen depletions, although the oxygen concentration was near zero in isolated areas shortly after sunrise on a few occasions. The level of fertility is similar to that of the lake. The West Slough was used as a spawning area by bowfin *(Amia calva)*, northern pike, carp *(Cyprinus carpio)*, golden shiner *(Notemigonus crysoleucas)*, largemouth bass, sunfishes, and Iowa darter *(Etheostoma exile)* and contained all species found in Lake George.

MATERIALS AND METHODS

Field work was conducted from June 10, 1955, to September 1, 1958, and in July 1959. Sac fry were obtained from nests by means of a plastic tube with ⅜-inch inside diameter. Fingerlings from the broods were collected with small dip nets, and after brood dispersal they were taken by use of a ¼-inch by 6- by 50-foot bag seine with a bobbinet liner (10 meshes to the inch) in the bag. Stations 3 and 5 in the lake were seined at weekly intervals and one station was maintained inside the West Slough entrance. All fish retained were preserved in 10 percent formalin. During the study 536 samples containing 8,571 fish were taken from lake and slough. Total length measurements were made on 5,490 fry and fingerlings, and weight measurements of 99 collections totaling 3,947 fry and small fingerlings and of 2,246 individual fingerlings were taken. Stomach analyses were made on 1,678 fingerlings taken in all years, and 526 stomachs were weighed. Estimates of abundance of largemouth bass fingerlings, I-annulus bass, and other species were made from weekly bag-seine hauls made at stations 3 and 5.

Analyses for dissolved oxygen were made with the unmodified Winkler method; for total alkalinity, with phenolphthalein and brom cresol green as indicators; and for pH, with a Hellige color comparator. Water tempera-

tures were measured by 8-day recording thermometers mounted on platforms in the lake and slough. In addition, maximum-minimum thermometers were used as a check at various locations, and temperatures were taken with a pocket thermometer as a routine part of field water analyses and bag-seine hauls. Illumination was measured by a 24-hour recording actinometer mounted on the thermometer housing in the lake.

GROWTH DURING FIRST SEASON

Growth in length

Spawning dates.—The first spawning of largemouth bass occurred 2-5 days after the daily mean water temperature reached and remained above 60° F. If the water temperature dropped after this initial period, additional spawning took place when the temperature rose again. In some years there were three separate spawning periods. Spawning dates extended from April 19 to June 2 in the 4 years of the study. In 1956 and 1958 separate spawning periods were not distinguished, and all fish in each of these years were combined for growth computations. Spawning dates in 1955 were estimated from size of fish taken in June, and all fish were considered to be the result of one spawning period. In 1957 there were two successful spawning periods, and the fish resulting from each were sufficiently different in size to require separate consideration. Growth of 10 groups of fish from the two areas in 4 years has been considered. The spawning dates of these groups were:

Group	West Slough	Lake George
1955	May 15	May 16
1956	May 20	May 20
1957 I	April 30	May 3
1957 II	May 26	May 27
1958	May 6	May 12

Total length, defined as the extreme tip length (Ricker and Merriman, 1945), was used in growth analysis. Sac fry and fingerlings less than 15 millimeters long were measured to the nearest 0.05 millimeter and larger fish to the nearest 0.5 millimeter. Body weight was measured to the nearest 0.005 gram. Fish less than 25 millimeters long were weighed by 1-millimeter size groups and average weights calculated.

The first season of life was divided into three stages for purposes of analysis. These stages are: 1) embryo, from time of fertilization to hatching of the egg and uncoiling of embryo; 2) sac fry, the time after hatching during which the fish obtain their nourishment entirely from the yolk sac (3-6 millimeters); and 3) fingerling, which begins when the fry rise from the nest and start to feed actively and continues to the end of the growing season (Figure 2).

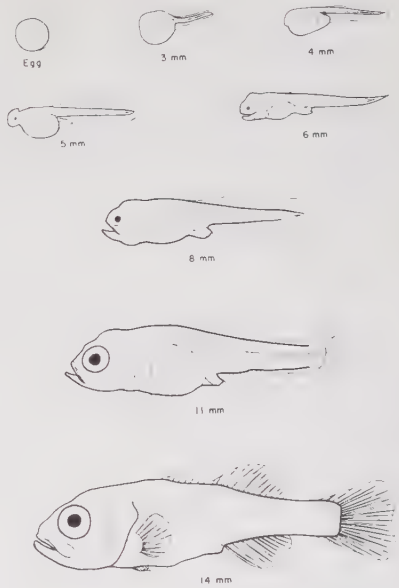

FIGURE 2.—Developmental stages of largemouth bass.

Embryo development.—The length of time required for bass eggs to hatch was measured in days from the date of egg deposition, which usually occurred in the early evening, to the date when the first sac fry appeared. Data from four spawning periods in each of the two areas showed that in six instances eggs began to hatch within 3 days and in two cases, 4 days were required (Table 1). These observations are in agreement with those made by Reighard (1905), who noted that 3-4 days were needed for hatching, and also with those of Page (1898), who stated that under experimental conditions, 70 hours to 4 days were required at a temperature of 63° F. or somewhat higher. Carr (1942) reported that 47-64 hours were required for hatching at water temperatures of 73-79° F. There seems to be some confusion in the literature as to what is meant by "egg hatching", since some authors

TABLE 1.—*Number of days and mean water temperature during embryo and sac-fry stages, mean length at rising, and growth rate of sac fry, West Slough and Lake George, 1956-1958*

Group	Embryo stage		Sac-fry stage			
	Days	Mean temperature (degrees Fahrenheit)	Days	Mean temperature (degrees Fahrenheit)	Mean length at rising (millimeters)	Growth rate (millimeters per day)
			West Slough			
1956	3	67.2	7	67.2	6.11	0.44
1957 I	3	62.2	7	63.2	6.24	0.46
1957 II	3	64.7	5	70.9	6.00	0.60
1958	4	62.3	6	68.1	6.25	0.54
Mean	3.3	64.1	6.25	67.4	6.15	0.51
			Lake George			
1956	3	62.8	8	62.7	5.92	0.42
1957 I	4	60.1	8	63.6	6.19	0.40
1957 II	3	66.5	6	69.5	6.31	0.55
1958	3	65.3	7	64.4	6.26	0.47
Mean	3.3	63.7	7.25	65.1	6.17	0.44
Grand mean	3.3	63.9	6.75	66.2	6.16	0.47

state 8-10 days to 3 weeks are needed. Apparently they refer to the total time from spawning to rising from the nest.

Sac-fry growth.—In 5 to 8 days after hatching, sac fry rose from the nest and started to feed on zooplankton. Mean total length at this time was 6.16 millimeters (Table 1). In all spawning periods for which data are available, fry grew faster in the slough than in the lake. The mean rate of growth of fry from slough nests was 0.51 millimeter per day and of those from lake nests, 0.44 millimeter per day. The most rapid growth in both areas was by the 1957 group II fish, and the slowest growth by the 1956 group and the 1957 group I fish. The mean number of days from egg hatching to rising of fry was 6.25 in the West Slough and 7.25 in Lake George.

Fingerling growth.—The bass fingerlings remained in individual broods for a period of 26-31 days and then dispersed. Mean total length at time of dispersal was 32.5 millimeters. After dispersal, emigration of slough fish to the lake started immediately and continued through the summer. The fingerlings remained at seining depths in the lake during the summer but began to leave the beaches by the end of August and were scarce by October.

Padfield (1951), using the scale method on mature fish, gave some indication that female bass grew faster than male bass in their first year, especially in environments where conditions for rapid growth were not present. In the present study male and female bass fingerlings captured from August 1 to the end of the growing season, when sex differentiation was positive, showed no significant differences in mean lengths during years of either good or poor growth. The sexes were, therefore, combined in all growth analyses.

Growth of fingerlings was expressed in curves of total length fitted by eye to points representing the average length of all fish in samples taken at 1- to 3-day intervals before the bass were 30 millimeters long and at weekly intervals thereafter (Figure 3). There was considerable variation in the growth patterns of the different groups in different years and areas. The total length at the end of the growing season and at the end of 2-week intervals after rising from the nest were estimated from the fitted curves (Table 2). The greatest observed total growth in a single season in both areas was made in 1955 and in the 1957 group I fish, while the least growth was made in 1956. The slough fish were longer than the lake fish at the end of each season except in the first 1957 group.

Variation in total length of fingerlings was considerable after brood dispersal (Table 3). The inherent variation was increased by both the range of spawning dates in any particular year and the movement of fish between the two areas. To minimize the effect of movement between areas, seining for bass was done at stations across the lake from the slough entrance.

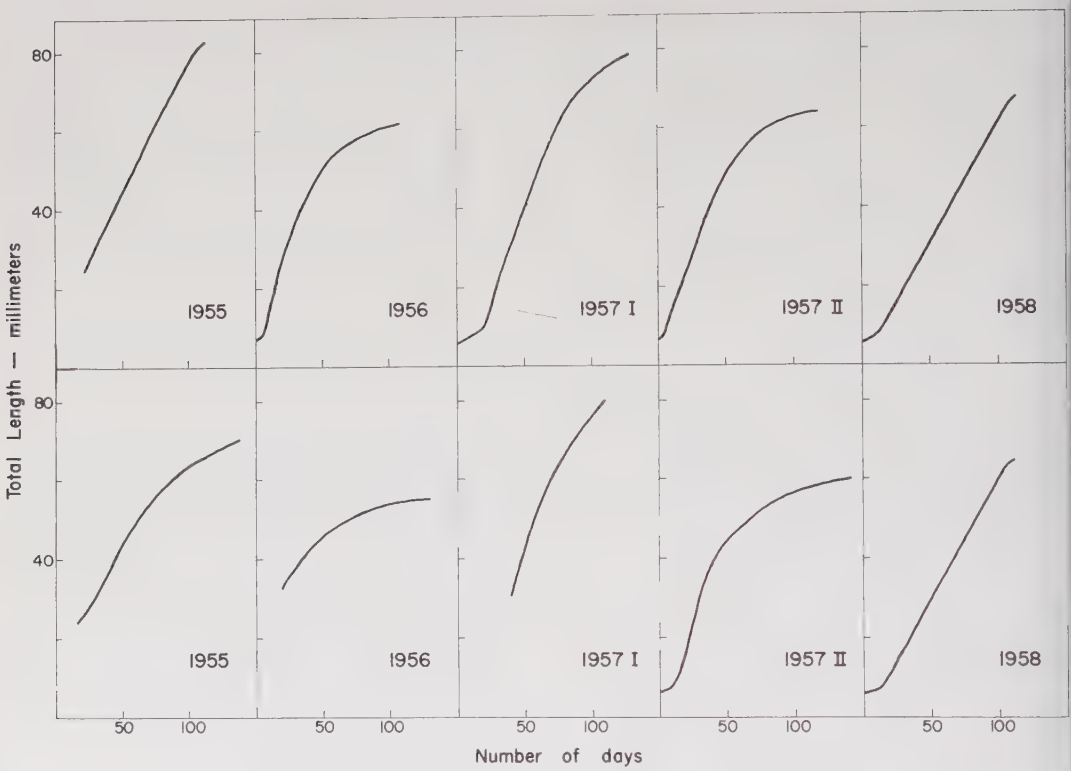

FIGURE 3.—Growth in total length of largemouth bass fingerlings, West Slough (above) and Lake George (below), 1955-1958.

TABLE 2.—*Total length in millimeters at successive 2-week periods, percentage of total growth attained on July 10 and August 1, and growth rate during each 2-week period, West Slough and Lake George, 1955-1958*

[Growth rate expressed as percentage increase in length and shown in parentheses. All lengths estimated from fitted growth curves.]

Weeks or item	West Slough					Lake George				
	1955	1956	1957 I	1957 II	1958	1955	1956	1957 I	1957 II	1958
2	— —	16.7 (173.8)	8.3 (33.9)	15.3 (155.0)	11.5 (82.5)	— —	— —	— —	10.7 (69.8)	9.3 (47.6)
4	28.7 —	34.3 (105.4)	15.8 (90.4)	28.3 (85.0)	19.5 (69.6)	29.7 —	36.3 —	— —	27.7 (165.4)	17.7 (90.3)
6	37.7 (31.4)	44.7 (30.3)	31.5 (99.4)	40.5 (43.1)	27.8 (42.6)	38.0 (27.9)	42.5 (17.1)	32.0 —	39.7 (43.3)	26.1 (47.5)
8	47.3 (25.5)	52.7 (17.9)	44.0 (39.7)	49.7 (22.7)	36.4 (30.9)	46.7 (22.9)	47.0 (10.6)	46.3 (44.7)	45.0 (13.4)	34.6 (32.6)
10	57.0 (20.5)	56.3 (6.8)	56.0 (27.3)	56.0 (12.7)	44.7 (22.8)	53.3 (14.1)	50.0 (6.4)	60.0 (29.6)	50.0 (11.1)	43.0 (24.3)
12	66.3 (16.3)	59.0 (4.8)	65.2 (16.4)	60.3 (7.7)	53.3 (19.2)	58.8 (10.3)	52.5 (5.0)	68.3 (13.8)	53.7 (7.4)	51.5 (19.8)
14	75.0 (13.1)	61.0 (3.4)	71.7 (10.0)	62.5 (3.6)	61.8 (15.9)	62.7 (6.6)	53.8 (2.5)	75.0 (9.8)	56.3 (4.8)	60.0 (16.5)
16	— —	62.0 (1.6)	75.5 (5.3)	63.5 (1.6)	— —	66.0 (5.3)	54.9 (2.0)	81.0 (8.0)	58.0 (3.0)	— —
Total growth	85.0	62.0	79.0	64.0	65.0	70.5	56.0	81.0	60.0	62.0
Percentage total growth by July 10	48.2	72.6	62.7	56.9	54.9	56.7	74.5	59.3	57.5	49.0
Percentage total growth by August 1	65.5	88.7	81.6	80.5	75.5	78.0	84.8	80.2	76.7	70.2

TABLE 3.—*Range and mean of total lengths of largemouth bass taken on July 15, August 1, and August 31, 1955-1958, West Slough and Lake George—expressed as millimeters*

Year group	July 15		August 1		August 31	
	Range	Mean	Range	Mean	Range	Mean
	West Slough					
1955....	43.0-59.0	53.6	47.5-69.0	61.0	54.0-84.0	72.7[1]
1956....	35.0-55.0	46.3	42.0-72.5	55.5	47.0-64.0	54.8
1957 I..	52.0-54.5	53.5[1]	58.0-70.0	63.6	66.0-73.0	69.3[1]
1957 II.	39.5-43.0	41.3[1]	43.5-49.0	46.1	51.0-64.5	58.9
1958....	31.0-45.0	39.1	38.5-52.0	45.5	60.0-73.0	66.0[1]
	Lake George					
1955....	39.0-52.5	45.3	47.5-66.5	56.5	50.0-81.5	60.2
1956....	35.0-53.0	41.5	42.0-57.5	47.6	44.5-69.0	53.0
1957 I..	51.0-58.0	54.4	61.0-73.0	65.5	64.0-111.0	71.5
1957 II.	27.5-45.0	38.9	33.0-55.0	45.4	45.0-63.0	55.5
1958....	26.0-42.0	33.9	28.0-47.0	39.8	50.0-65.0	58.9

[1]Less than five fish.

In order to compare growth in different years, the rate of growth during each 2-week period was expressed as the percentage increment to the total length at the beginning of the period (Table 2). Growth rate was highest during the first, second, or third 2-week period and then progressively decreased. This decrease was more pronounced in 1956 and in the 1957 group II fish in both areas. Growth rates were high for a longer period in 1955 and 1958 in the West Slough and in 1958 in Lake George.

The percentage of total annual growth completed by July 10 varied from 48 to 75 percent and that completed by August 1 from 66 to 89 percent (Table 2). The ranking of the 10 groups on the basis of total length attained by July 10 was significantly different from the ranking made from total growth at the end of the season (5 percent level, Chi-square). The ranking on the basis of total length reached by August 1, however, was not significantly different from that at the end of the season. Total growth for the season, therefore, appears to be contingent upon the size attained by August 1, and not upon that reached early in July, as Smith and Pycha (1960) found to be the case with first-year growth of the walleye *(Stizostedion v. vitreum)*.

Length-weight relationship

The length-weight relationship of older fish has been satisfactorily described in various species by the formula

$$\log W = n \log L + \log c,$$

where W = weight, L = length, and c and n are constants. Preliminary scanning of the data suggested that a single set of constants could not be used to describe the length-weight relationship in largemouth bass during the first season of growth. Plots of lengths and weights showed that there were three stanzas of relative growth in weight (Figure 4). The first was between the lengths of 3.00 and 6.40 millimeters, the second between 6.45 and 11.95 millimeters, and the third between 12.00 and 80.0 millimeters total length. The first stanza was from shortly after hatching to the time of yolk-sac absorption; the second was between yolk-sac absorption and the time that

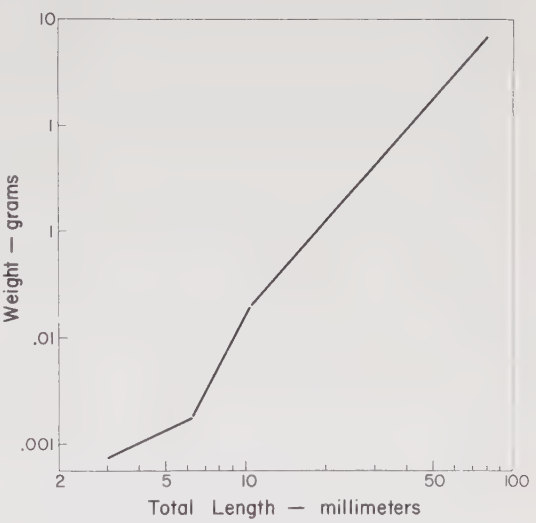

FIGURE 4.—Length-weight relationships of largemouth bass from all collections in Lake George and West Slough.

the caudal fin assumed its adult homocercal form (Figure 2); and the last included the remainder of the first growing season. Computation of regression lines by the method of least squares was made from the logarithms of the mean lengths and weights of 34 samples representing 1,415 fry in the first stanza, of 65 samples representing 2,532 fingerlings in the second stanza, and from logarithms of lengths and weights of 2,246 individual fingerlings from 25.0 to 80.0 millimeters total length in the third stanza. Since fish between 12.00 and 24.5 millimeters were not taken in all year groups and extrapolation to lengths in this range fitted the calculated regressions closely, they were omitted from the calcula-

tions. The regression lines fitted to each stanza were:

Fish length (millimeters)	Regression
3.00 — 6.40	Log W = 1.34337 log L — 3.79828
6.45 — 11.95	Log W = 3.89555 log L — 5.80130
12.00 — 80.0	Log W = 2.96211 log L — 4.79809

where L = total length in millimeters and W = body weight in grams.

The rate of increase in weight with length was the slowest during the sac-fry stage and most rapid from the time of rising and beginning of feeding to the length at which the caudal fin assumed its adult homocercal form. During the last stanza the rate of increase in weight was slightly less than the cube of the length.

The length-weight relationships of fish from the different areas and years were compared by using relative condition factor *(K_n)* of LeCren (1951):

$$K_n = \frac{W}{W_1}$$

where W = weight at capture and W_1 = weight calculated from the length-weight regression.

No differences among year groups could be shown during the first two growth stanzas (3.00-6.40 millimeters and 6.45-11.95 millimeters). In the last stanza (12.00-80.0 millimeters) relative condition factor *(K_n)* for each fish was computed. Since distribution of K_n for any one year group was approximately normal, means were calculated (Table 4). In some groups the relative condition factor increased with the size of fish, but means calculated from the K_n of fish combined in successive 10-millimeter intervals were not significantly different from means of the distribution of the entire group.

Mean relative condition factors varied from 0.918 to 1.067, and in all year groups the fingerlings from the West Slough were in higher condition than those from Lake George. Toward the end of the growing season marked differences in body structure between fish from the two areas were evident with those from the slough being deeper bodied (Figure 5). Fingerlings from both areas were in the best condition in 1955 and 1958, and poorest condition in 1956 and 1957. In any single year the mean condition factors in the two areas were significantly different at the 5 percent level (t test), and all differences among years within areas were significant with the exception of the 1955 and 1958 groups in both areas and the 1957 I and II groups in the slough.

FIGURE 5.—Specimens of bass fingerlings from West Slough (above) and Lake George (below) collected on September 10, 1957 (slough fish: 66 millimeters, 4.48 grams, relative condition factor, 1.147; lake fish: 65 millimeters, 3.32 grams, relative condition factor, 0.890).

TABLE 4.—*Mean relative condition factors (Kn) of largemouth bass fingerlings 25.0 to 80.0 millimeters total length, West Slough and Lake George, 1955-1959*

[Number of fish in parentheses]

Year group	Mean relative condition factor	
	West Slough	Lake George
1955	1.067 (193)	1.029 (320)
1956	0.979 (249)	0.940 (340)
1957 I	1.007 (66)	0.918 (60)
1957 II	0.993 (160)	0.964 (606)
1958	1.059 (133)	1.036 (119)
1959	——	0.985 (144)

Rate of growth and condition

Many studies have shown that the fastest growing fish were also in the best condition (Brown, 1946; Stroud, 1949; Hansen, 1951; Cooper, 1953). Hile (1936) found that in the cisco *(Leucichthys artedi)* the most rapidly growing fish had the highest K factor but the slowest did not have the lowest K factor. Smith and Pycha (1960) found in young-of-the-year walleye of Red Lakes, Minnesota, that the mean relative condition factors of all fish larger than the mean length in each sample

were significantly higher than those of fish shorter than the mean length. In the present study the mean relative condition factor of bass fingerlings from the upper half of the length distribution in individual samples was compared to that from the lower half of the distribution. In 29 of 37 samples taken from the West Slough during the 4-year period it was found that the larger fish were in better condition than the smaller fish. This difference was significant at the 1 percent level with the sign test. In only 12 of 33 samples from Lake George, on the other hand, were the larger bass in better condition. This difference was not significant. Total growth for the entire season and the mean relative condition factor for each group were compared and there was no apparent relationship.

FACTORS ASSOCIATED WITH RATE OF GROWTH

Water temperature

Embryo development.—The time required for hatching of bass eggs was 3-4 days when the mean daily water temperature was 63.9° F. (Table 1). During the two periods when 4 days were required, mean daily water temperature was 60.1° F. and 62.3° F., while during the periods when 3 days were required, mean daily water temperature varied from 62.2° to 67.2° F. On the basis of these observations it is apparent that time required from fertilization to hatching of bass eggs was inversely related to the mean temperature, as has been observed in other studies of fish embryo development.

Sac-fry growth.—At the time of hatching all groups of sac fry were 3 millimeters long, but when they rose from the nest the mean length varied from 5.92 to 6.31 millimeters. The mean growth rate was from 0.40 to 0.60 millimeter per day, while the mean daily water temperature during the 5- to 8-day period varied from 62.7° to 70.9° F. (Table 1). A significant correlation (r=0.885, 1 percent level) between growth rate and mean daily water temperature was found. Since young bass during this period are absorbing the yolk sac and are not able to leave the nest, temperature might be expected to have a significant influence upon the rate of metabolism and, therefore, upon rate of growth. The mean length of the combined egg and sac-fry period was 10 days, and the mean daily water temperature for this period was 65.4° F. Huet (1952) states that the incubation period (presumably embryo and sac-fry stages combined) was 10 days at a temperature of 18° C. (64.4° F.).

Fingerling growth.—During the first and second 2-week growth periods rate of growth and mean daily water temperature were compared in the West Slough, and significant positive correlations were found in both periods ($r = 0.995$, 1 percent; $r = 0.948$, 5 percent; periods 1 and 2, respectively). During this time mean length increased from 6.00-6.25 millimeters to 15.8-34.3 millimeters. In periods 3 to 8, during which lake and slough data were combined, a significant correlation was found in only the eighth period ($r = 0.937$, 1 percent level) when mean length increased from 53.8-75.0 millimeters to 54.9-81.0 millimeters. These relationships suggest that between the time of brood dispersal and the end of the growing season, the effects of mean water temperature on growth rate are obscured by other factors, the bass experience temperatures different from those recorded, or temperatures exceed optimum levels during parts of the summer.

Total temperature experience, expressed as accumulated degree-days above 50° F., of fish on August 1 (8-12 weeks after rising), at the end of 14 weeks' growth, and at the end of the growing season, was compared with total length attained at the respective times, and a significant relationship was found only in the comparison made on August 1 ($r = 0.804$, 1 percent level). This suggests that total season's growth is strongly associated with the total temperature experience before August 1, and is influenced little by temperature after this date.

Illumination and water chemistry

Daily illumination and accumulated illumination in langleys were compared to embryo, sac-fry, and fingerling growth, and no important relationships were noted. Since it was not possible to show significant relationships between growth and amount of light, it is believed that if any exist they are masked by other factors.

Dissolved oxygen, total alkalinity, and hydrogen-ion concentration were determined daily during the embryo and sac-fry stages in both slough and lake and at 2- to 3-day intervals thereafter. No extreme variations

were noted and no relationship between these chemical characteristics and growth could be shown.

Abundance of young bass

Bass fingerlings were present at seining depths in the lake after brood dispersal and could be captured with a bag seine throughout the summer. Weekly catches made with a 50-foot bag seine at stations 3 and 5 were fitted with linear regressions and compared by the simplified covariance procedure outlined by Ostle (1954, p. 133). It was found that the 1955 and 1958 year classes were significantly lower (5 percent level) in numerical strength than the 1956 and 1957 year classes, but that the latter two classes were not different from each other (Table 5). Seine catches made at the West Slough outlet, numbers of successful nests, and estimated numbers of fingerlings in the broods before dispersal confirmed this ranking of the year classes. Abundance of bass fingerlings appeared to have no influence upon the rate of growth at any period of time or upon the total length at the end of the first 14 weeks of the growing season. It was observed, however, that low abundance was coincident with high condition factor in all years.

TABLE 5.—*Estimated abundance of largemouth bass fingerlings at the time of brood dispersal and of I-annulus bass on June 10 at stations 3 and 5, Lake George, 1955-1959—expressed as numbers per 1,000 square feet*

Year	Seining period	Number	
		Fingerlings	Yearlings
1955	June 16 - October 25	1.0	0.94
1956	June 16 - September 27	5.5	0.05
1957	June 20 - September 10	10.0	0.42
1958	June 16 - August 28	1.3	0.93
1959	July 6 - July 31	8.0	<0.05

Largemouth bass yearlings (I-annulus) were present in the seining depths during the entire summer, and the bag-seine catches reflected the same relative strengths of year class as the previous year's young-of-the-year catches (Table 5). The estimated abundance of yearling bass at the beginning of the summer varied from less than 0.05 to 0.94 fish per 1,000 square feet of shoal area. Although the bass yearlings occupied the same area as the fingerlings, their numbers had no apparent effect upon the fingerling growth.

Abundance of other species

Other species of fish in Lake George which may compete with the largemouth bass fingerlings for food and space were sunfish and perch fingerlings and yearlings, minnows, darters, and other forage species. They were sampled during the seining for bass at stations 3 and 5. All groups of fish were weighed and the average weights of sunfish, perch, and forage fish per seine haul were calculated (Table 6). The average weight of other species varied from 1.50 to 3.67 pounds per seine haul (approximately 6,000 square feet) in different years. The abundance of these other fishes could not be related to total growth of bass at the end of the season, nor was any influence upon their condition apparent. In years of both lowest and highest abundance of other fishes bass fingerlings had lowest relative condition (K_n).

TABLE 6.—*Average weight of sunfish and perch fingerlings and yearlings, and forage species taken per 50-foot bag-seine haul (6,000 square feet), stations 3 and 5, Lake George, June 16 to August 31, 1956-1958—expressed in pounds*

Species	Year		
	1956	1957	1958
Sunfish	—[1]	2.08	1.40
Perch	0.98	1.56	0.75
Forage[2]	0.52	0.03	1.00
Total	1.50	3.67	3.15

[1]Included in forage.
[2]Includes cyprinids, darters, banded killifish (*Fundulus diaphanus*), and brook silverside.

Food habits

Relationship to growth in length.—Stomachs of bass fingerlings were examined from the time they rose from the nest until the end of the first growing season. In the 4-year period, 1955-1958, 122, 227, 252, and 139 stomachs of bass from the West Slough, and 212, 274, 322, and 130 of bass from Lake George in the respective years were examined. Food organisms identified to genera which were found in the stomach contents included 9 algae, 1 Protozoa, 10 Rotatoria, 1 Oligochaeta, 17 Cladocera, 3 Copepoda, and 1 Amphipoda. Members of 25 families of insects representing 7 orders, 2 other orders of insects, 10 species of fish, and occasional unidentified Hirudinea, Ostracoda, Hydracarina,

and Gastropoda were also found in stomachs of bass fingerlings.

The diet of newly risen fingerlings was composed chiefly of nauplii, rotifers, small cladocerans, and rarely algae. After the fingerlings reached a total length of 30 millimeters, rotifers were no longer eaten and in fish over 60 millimeters nauplii were not found. As the fish increased in size, their diet shifted from the smaller organisms (cladocerans, copepods, and rotifers) to the larger forms *(Hyalella,* immature and adult insects, and fish) (Table 7). Very few stomachs contained fish, and most of these were from bass captured in the lake. This low utilization of fish was probably due to the relatively low abundance of small forage species and to the fact that the more abundant forage fish, which spawned at the same time as the bass, produced young that grew at the same rate as the bass and were therefore not available as food. The fish most commonly taken were young-of-the-year sunfish and brook silverside *(Labidesthes sicculus).*

During the first and second 2-week growth periods an index of the total food eaten was derived from the average number of microcrustaceans contained in the stomachs. Since these organisms were of approximately the same size and because accurate measurement of stomach contents was difficult and subject to error from different digestion rates and small total volumes, counts were believed to be the most useful measure. During the first growth period there was a significant correlation ($r = 0.868$, 5 percent level) between number of microcrustaceans contained and growth rate. During the second growth period, however, significant correlation was not found. Comparisons of numbers of organisms in the stomach and rate of growth after the first two growth periods were not made because there was a wide range in size of organisms eaten.

In 1958, a year when the growth rates were nearly the same in both areas throughout the season, stomach weight was compared to body length and weight. Weights of stomachs taken from fish caught during the afternoon were stratified by the 2-week growth periods. Regression lines were fitted to log-log plots of stomach weight versus body length and stomach weight versus body weight, as follows:

West Slough (88 fish)

$$\text{Log } Z = 3.1045 \log L - 3.5064$$
$$\text{Log } Z = 1.0041 \log W + 1.5016$$

Lake George (91 fish)

$$\text{Log } Z = 2.5067 \log L - 2.6324$$
$$\text{Log } Z = 0.8359 \log W + 1.4328$$

where L = total length in millimeters, W = total body weight in grams, and Z = stomach weight in milligrams.

The members of each pair of regressions were significantly different at the 5 percent level (covariance analysis), and the stomachs from slough fish were heavier per unit body

TABLE 7.—*Average numbers of major food items per stomach contained in largemouth bass fingerlings grouped by 10-millimeter total length intervals, West Slough and Lake George, 1955-1958—expressed as unweighted means for all years*

Item	Total length								
	6.0–9.9	10.0–19.9	20.0–29.9	30.0–39.9	40.0–49.9	50.0–59.9	60.0–69.9	70.0–79.9	80.0–up
West Slough									
Rotifers	4.8	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Microcrustacea	23.8	35.1	101.1	83.0	29.7	11.7	9.7	1.8	0.0
Hyalella	0.0	0.0	T[1]	0.3	0.3	0.5	0.6	0.6	0.2
Insects	T	0.4	1.0	1.8	1.2	8.1	8.6	9.0	2.6
Fish	0.0	0.0	T	0.1	T	0.1	T	0.0	0.0
Lake George									
Rotifers	5.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Microcrustacea	10.8	66.6	22.6	52.9	54.7	35.9	11.6	6.5	7.0
Hyalella	0.0	0.0	0.4	1.0	1.0	0.6	0.7	0.3	0.1
Insects	0.0	0.6	2.7	2.9	1.7	5.8	5.6	1.6	5.4
Fish	0.0	0.0	0.2	0.2	0.1	0.1	0.3	0.1	0.3

[1] T = less than 0.05.

length or weight than those from lake fish. Since the growth rates of fish in the two areas were nearly identical, the increased amount of food contained in the stomachs of fish from the slough had no apparent influence upon the rate of growth.

An index to the quality of food taken was obtained from the ratio of small organisms (microcrustacea) to numbers of large organisms (insects, *Hyalella*, and fish) contained in stomachs. The growth rate (percentage increment) and this ratio were compared in each 2-week period for all 10 groups of fingerlings in the study, and a significant relationship was found only in the seventh period when there was a strong negative correlation ($r = -0.856$, 1 percent level), although an increased negative trend was apparent after the fourth period. These findings suggest that the bass fingerlings which fed on a higher proportion, by number, of larger organisms may grow at a faster rate than other fingerlings, particularly toward the end of the first growing season.

Relative condition.—It has been shown above that in all years the fish taken from the slough were in better condition than those taken from the lake, and also that the highest condition factors (K_n) in both areas were found in 1955 and 1958. The relationship of food to these differences was examined by comparison of stomach weight-body weight regressions computed from afternoon-caught fish from each area in all years, as follows:

Year	Number	West Slough
1955	47	$\log Z = 0.8367 \log W + 1.4761$
1956	42	$\log Z = 0.8628 \log W + 1.4908$
1957	30	$\log Z = 0.9569 \log W + 1.4466$
1958	88	$\log Z = 1.0041 \log W + 1.5016$
Year	Number	Lake George
1955	65	$\log Z = 1.0111 \log W + 1.4278$
1956	63	$\log Z = 0.9275 \log W + 1.4409$
1957	100	$\log Z = 0.8343 \log W + 1.3983$
1958	91	$\log Z = 0.8359 \log W + 1.4328$

where W = total body weight in grams and Z = stomach weight in milligrams.

Covariance analyses indicated that in 1955 and 1958 the regression lines from the two areas were different at the 5 percent level. No significant difference was found in 1956 or 1957, both years when the sample from the slough was small and did not cover the whole range of body lengths. Although significant differences were not demonstrated in all years, visual comparison of the plotted lines showed that stomach weights in the slough were higher than those in the lake throughout the greater part of the range. These observations suggest that in any single year the better condition of fish in the West Slough resulted from more food in the stomach per unit of body weight.

The regressions for different years within a single area were compared through covariance analysis. In the slough it was found that 1955 was significantly different from 1958 (5 percent level), and in the lake that 1955 was significantly different from 1957 and 1958 (1 percent and 5 percent levels, respectively). These differences were related to the slopes of the regression lines. In the slough, stomachs were lightest in 1955 and heaviest in 1958, while in the lake they were lightest in 1957 and 1958 and the heaviest in 1955. Since the trends from light to heavy stomachs in successive years proceeded in opposite directions in the two areas, and both the lightest and heaviest stomachs occurred in the 2 years of high condition factor, differences in stomach weight do not appear to explain differences in relative condition within a single area.

CONCLUSIONS

Patterns and rates of growth in largemouth bass were highly variable, and the differences observed in length at the end of the first growing season could not be related to the ecological factors considered. During the embryo and sac-fry stages, water temperature was the factor most closely associated with the rate of development. In the first 4 weeks after the fingerlings rose from the nest and again near the end of the growing season, water temperature was directly related to growth rate, but during the 10-week period which intervened no relationship could be demonstrated. Total length at the end of the season was clearly indicated by the size of the fish on August 1, and length on this date was strongly related to accumulated temperature experience. Habitat conditions existing during the remainder of the growing period did not appear to alter the rank of the particular year with reference to relative goodness or poorness of growth.

Differences in relative condition of fish in the two areas in single years appeared to be related to differences in stomach weight, but the differences among years within areas were not caused by changes in stomach weight.

Abundance of bass fingerlings was inversely related to the annual differences in condition, but the mechanism of this relationship was not defined.

The amount of food eaten appeared to be related to rate of growth only during the first 2 weeks after fish rose from the nest. Inability to show relationships thereafter may stem from the fact that stomach contents were not an adequate index of daily food utilization and assimilation during the warmer periods of the growing season. Comparison of growth rate and size of food items eaten suggests that selection of larger food items results in an increased growth rate, especially as the season advances. A more precise evaluation of the influence of changes in food intake will require better definition of food taken during a 24-hour period and the influence of temperature on metabolism at the higher temperatures existing in the warmest parts of the summer.

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Management of Sport Fishing in National Parks[1]

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ABSTRACT

The National Park Service, entrusted with the perpetuation of natural aquatic conditions in areas it administers, manages recreational fishing so as to create minimum disturbances to these resources. In national parks and monuments angling cannot be managed independently of other park uses and features of significance. The objectives of the conservation of park fishery resources differ in some respects from those which govern programs in waters located outside park areas. The policy and program for the management of sport fishing are outlined.

Fishery resources of the national parks and monuments of the United States are part of the great heritage entrusted to the National Park Service to preserve and perpetuate for present and future generations. Management entails the safeguarding of these resources while providing recreational angling for limited numbers of park visitors who fish.

Recreational angling is a recognized use of these natural resources. This use may appear to be a deviation from the fundamental conservation concept that all forms of wildlife within the national parks and monuments shall receive full protection. In reality, angling is provided for by law in some parks, by rules and regulations in others, and by tradition throughout the Service. Commercial fishing is permitted in a few parks, also.

Birds and mammals of Yellowstone National Park receive full protection by the law of 1894 which specifically prohibits the killing of these animals while providing for the catching of fish by the use of hook and line only. In addition, it directs ". . . that the Secretary of the Interior . . . shall make rules and regulations governing the taking of fish from the streams and lakes in the park." Similar provisions are contained in legislative actions which relate to the establishment of many other national parks. Consequently, fishing is a park-visitor use which dates from the creation of the first national park in 1872.

The law which established the National Park Service in 1916 endowed it with this responsibility: ". . . to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." The Service has developed a policy and program which provides for recreational fishing consistent with these primary objectives.

In areas such as Lake Mead and Shadow Mountain National Recreation Areas, where recreational activities are administered by the National Park Service, we cooperate with state agencies and the Bureau of Sport Fisheries and Wildlife in the management of the fishery resources. In national parks and monuments the National Park Service assumes the primary responsibility for the management of sport fishing.

A critical evaluation of fishery resources to determine needs for research, investigations, interpretation, and management is now being conducted. The place of recreational angling in the scope of visitor activities also is being reviewed.

The program is directed toward:

1. The determination of original and present aquatic conditions.

2. The perpetuation and restoration of native fishes, natural aquatic conditions, and associated plants and animals.

3. The protection of wild fish populations. (Wild fish are defined as native or exotic fish which have been naturally produced or which have been stocked during previous seasons as fingerlings. In contrast, put-and-take fish are recognized as hatchery fish introduced for the purpose of being caught immediately or during the current season.)

4. The provision of an opportunity to fish for wild, colorful, vigorous trout amid surroundings which remain as nearly natural as possible. This activity is to be conducted in a manner that shall create minimum interference with wildlife

[1]Presented as part of the symposium on *Management of Natural Lakes* at the Eighty-Ninth Annual Meeting of the American Fisheries Society.

or features of scenic, scientific, or historic importance or with the enjoyment of these features by other park visitors.

5. The management of present resources through methods such as limited stocking, fishing regulations, and law enforcement and by the use of information secured through investigations and records of angler-use activities. Primary reliance for fish for the angler will be placed upon the natural reproductive capacities of wild fish populations rather than upon planting of artificially reared fish.

6. The creation of greater appreciation of the aquatic resources through the interpretation of these features to the park visitors.

The history of management of fishery resources in many lakes and streams now within national parks is similar to that for other waters throughout the nation. The significance and importance of preserving native fish faunas and original conditions have not always been appreciated in the past.

Exotic fishes have been introduced into waters which were originally barren and into waters containing only indigenous fishes. Such introductions were made by intentional stocking, invasion of exotics from waters outside park boundaries, and unauthorized releases of bait fishes. Although the exotics failed to take hold in some waters, they became established in other locations. As a result of predation by and the competition and hybridization with the introduced forms, the endemic fish faunas have become greatly altered. Initial and subsequent stocking operations have left relatively few waters untouched. Into other park waters, the free movement of native migratory species has been restricted or completely cut off by the construction of dams. Further changes in aquatic environments and alterations in the distribution and composition of fish populations have resulted from the creation of artificial impoundments adjacent to some parks.

Acute and drastic modifications of many original habitats and fish faunas have thus occurred within the parks. Fortunately, some very significant waters and fish faunas still exist under relatively undisturbed conditions. Because relatively few natural unaltered aquatic environments are found throughout the country, the Service recognizes a special opportunity to preserve the natural habitats and native fishes found in park areas.

Fresh-water lakes and streams found in national parks and monuments are classified in two groups. The first group consists of waters which originally contained native fishes. In some the fish populations still exist in a virtually natural state; in others, exotics have been introduced and both the alien and native fishes are present; in still others, the exotics have completely replaced the native fish faunas and exist by natural reproduction. The second group concerns waters which were originally barren. Some are still without fish life; many are maintained by self-supporting populations of exotic fishes; and others support fish only by periodic stocking.

The eventual objective of the Service is to restore native fishes to their natural waters wherever and whenever feasible. Such a restoration program entails studies of specific waters to evaluate the current fish populations. In most cases, exotic fishes must be eliminated before native forms may be returned. Sport and non-sport fishes will be given equal consideration in any re-establishment plan. Restoration may be achieved by natural or artificial methods.

In Great Smoky Mountains National Park, for example, the introduced rainbow trout *(Salmo gairdneri)* in Indian Creek were eradicated by chemical treatment and the Appalachian strain of brook trout *(Salvelinus fontinalis)* restored. A few other waters in the National Park system have also been reclaimed by this method. The future of this procedure shows promise on a selected basis, but wholesale elimination of exotics and restoration of indigenous species probably is not feasible.

Natural rehabilitation of a native population is encouraged. An example of this is taking place in Shenandoah National Park where a series of climatic events reduced the populations of native brook trout. Severe droughts in 1953 and 1954 caused the streams to diminish in size, and the dry seasons were followed by the hurricane torrents which scoured the stream courses. In order to preserve and restore the remnant native fish populations, the streams were closed to fishing. During this period of closure the surviving brook trout began to replenish the waters. When the streams were reopened, the size limit was set at 9 inches and fishing was allowed only with single-hooked lures. Now the streams abound with wild and brilliantly colored native brook trout. Adjust-

ments of the size and creel limits in future years will be based on known population characteristics.

It is recognized that reclamation of all streams and lakes is impractical by the use of current techniques. Where restoration is deemed infeasible, therefore, the existing native and introduced fishes are managed as wild populations. Maximum reliance upon natural reproduction is stressed. In lakes and streams which originally were barren and in which natural reproduction is limited or lacking, stocking may be employed to supplement current fish populations. Lakes which are now barren are preserved in this original condition.

Many animals utilize fish in their normal diets. To limit or restrict this natural use of the fishery resources is not undertaken even in the interest of protecting sport fishes unless the fish species are in danger of extinction. Under such a program angling within national parks and monuments cannot be managed independently of other park uses and values. This sport is recognized as an incidental park recreational activity. The primary purpose of a visit to a park is the enjoyment of all natural features for which that individual park was created. Often procedures used to preserve park fisheries are different from methods employed to manage the resources outside park areas. The objectives of each program must be considered before each type of management is understood and appreciated.

Following the national trend, numbers of anglers have increased within the national parks and monuments. Specific natural characteristics of any lake or stream limits the number of fish which can be naturally supported. The catch, therefore, must be regulated within the bounds of this natural productivity. Measures being used to protect wild fishes on specific waters are: lower creel limits, higher size limits, and fishing-for-fun-only and fly-fishing-only regulations. They are providing the desired results.

A creel limit often is interpreted as a goal which an angler must achieve to be considered successful. This objective often results in the taking of excess fish and consequent waste. In keeping with its special objectives, the Service discourages the consideration of creel limits as goals to be achieved and has experimented with low creel limits, the return of uninjured fish, and the taking of only enough fish for camp use.

Park officials in Great Smoky Mountains National Park are experimenting with fishing-for-fun-only regulations on four streams as part of a research program conducted in cooperation with the U. S. Fish and Wildlife Service. The angler may fish the year around, catch all the trout he can on single-hooked artificial lures, but he is required to release all fish under 16 inches. He may keep the larger trout as trophy fish. On these waters recreation is the primary objective and the enjoyment of angling comes from the luring of wild trout and not from retaining the catch. Under this system anglers can catch more fish per hour without damage to the basic resources. It is a means of limiting the kill rather than the catch and of coping with high fishing pressure without resorting to measures that would lower the quality of the fishing experience. In other park waters, where the carrying capacity is low, such as the Ohanapecosh River in Mount Rainier National Park, angling is restricted to fly-fishing-only. The use of live or natural baits often is prohibited to limit the harvest and to prevent the introduction of non-native animal life.

On Yellowstone Lake in Yellowstone National Park, where the future of the cutthroat trout *(Salmo clarki)* must be insured, the creel limit is three fish per day. Under such restrictions the population is withstanding the strain of ever-mounting pressure.

Hatchery trout are released into some park waters to supplement natural reproduction and to help sustain angling for wild fish. It is not our policy to provide put-and-take fishing. The stocking of catchable trout for immediate return to the anglers is not compatible with the fundamental objectives of the National Park Service fishery management program. Plantings of this nature tend to attract fishermen who are primarily interested in fishing rather than in the overall enjoyment of basic park features. First priority in stocking programs is given to native fishes. In waters where exotic species have become established and where the restoration of native species is impracticable, these waters are managed by methods comparable with those employed for native species.

Lakes within national parks and monuments are managed according to their specific characteristics. When stocking is needed in trout lakes, fingerlings are planted. Such releases are made according to demonstrated requirements. To prevent indiscriminate planting, definite management programs are established. Where natural reproduction is limited, such evaluations frequently are difficult. In lakes where natural reproduction is absent, the success of previous plantings is used as a guide for future stocking. In Yosemite National Park, for example, there are over 200 high-country lakes which contain trout. They are now managed according to a 10-year plan. Lakes which contain adequate supplies of trout are not restocked. The other lakes are managed on a maintenance basis. Those which receive heavy fishing are stocked annually or biennially, according to their individual requirements.

Back-country lakes receive lighter fishing pressures. Plantings of rainbow trout are made on a rotation system. Under this system the lakes are restocked every 5 to 7 years. This practice provides for maximum growth of planted fish because the factor of competition between age groups is reduced or eliminated. Where several lakes occur in an individual basin, not all are planted in a single season. Good fishing can thereby be had in one or more of these lakes each year. Formerly, when pack stock was used to transport the fish, it was necessary to plant all lakes within a given basin at one time. The cooperation of the California Department of Fish and Game in planting these trout by airplane makes the present program possible. By stocking smaller numbers of trout the individual fish make faster growth. Past overstocking resulted in slower growth and smaller trout — a condition which could not be corrected until the population became drastically reduced. This process usually takes several years. Information on the relative success of each planting is now obtained through follow-up investigations and angler creel census. By having a definite plan for fishery management of the lakes of Yosemite, the National Park Service is perpetuating wild trout fishing. Similar programs are being developed in other national parks.

State fishing licenses are required in a number of parks and all monuments, but they are not necessary in some parks where exclusive jurisdiction is exercised. This requirement generally is governed by the type of legal authority by which a specific area was established.

In the management of its fishery resources the National Park Service enjoys the cooperation of the U. S. Fish and Wildlife Service and state fish and game departments. Although final determinations of stocking requirements are made by the National Park Service, fish planted in park waters are provided by the U. S. Bureau of Sport Fisheries and Wildlife or by the states. The actual planting operations usually are cooperative undertakings. The Service receives assistance and advice in fishery research and management investigations from the Fish and Wildlife Service, state agencies, educational institutions, and private organizations. Cooperative research is welcomed and encouraged in both marine and fresh-water biology. Most parks afford ideal conditions for such study, and we believe the value of these park waters for research will continue to increase.

The interest of the National Park Service in its fishery resources extends beyond the utilization of sport fishes by anglers. The fish fauna is a vital part of the natural history of an individual area, and its proper interpretation to the park visitor is an important function of the Service. Species which are of little interest to the angler may be of greater significance ecologically and biologically than sport fishes. The isolated Cyprinodon fishes of Death Valley National Monument, for example, provide living evidence of past geological happenings. A unique mosquito fish of Big Bend National Park, Texas, is near extinction, and this has caused concern in recent years. A highly specialized chub initially discovered in Grand Canyon National Park may become extinct as water conditions in the Colorado River are modified by the construction of Glen Canyon Dam. The blind fishes of Mammoth Cave National Park, Kentucky, are of special interest to visitors and scientists alike.

Information on the native fish faunas of most parks is meager. Significant studies have been conducted in some of the areas; but, as in other waters throughout the country, additional research is required to complete knowledge necessary for intelligent management.

Sport angling of national significance for wild fishes can be perpetuated and native

fishes and natural aquatic conditions can be preserved in national parks through proper management. Through interpretive programs, appreciation and interest in the aquatic life will extend to all park visitors. The Service is looking forward to developing closer cooperation with the states and other federal agencies to provide a well-balanced recreational, interpretive, and scientific conservation program for the fishery resources.

SHORT PAPERS AND NOTES

Observations on the Stomach Contents of the Silver Hake

The available published reports on the food habits of silver hake, *Merluccius bilinearis* (Mitchill), place great emphasis on the importance of fish as a food item of this species (Goode, 1884; Nichols and Breder, 1927; Bigelow and Schroeder, 1953). Invertebrates, if mentioned at all, are considered secondary as food items. The purpose of this note is to present the results of some observations of the contents of silver hake stomachs collected in the waters off the northeast coast of the United States. These data were collected incidentally to other studies and are not intended to serve as a definitive report on the food habits of the species. Because there is a scarcity of such reports, however, we wish to place our observations on record.

The fish were caught by otter trawl and the fork length of each was measured. The stomachs were removed, the contents identified, and the frequency of occurrence of food items was recorded by counting the number of stomachs in which that food item was found. A stomach which contained, for example, both fish and Crustacea was counted twice, once for fish and once for Crustacea. The method of recording stomach contents by frequency of occurrence does not take into account the sizes of the food items involved and thus equates, for example, one fish and one shrimp. This method affords only a rough indication of the food habits of the animal. A total of 348 silver hake stomachs was examined, of which only 153 (44 percent) contained food. The stomach-analysis data are listed in Table 1.

Sample 1 was collected in August 1954 northeast of Provincetown, Massachusetts (lat. 42° 08′ N., long. 70° 05′ W.), in 26 to 36 fathoms of water. The sample consisted of 111 fish with a range of 23 to 62 centimeters in length. Twenty of these fish had food in their stomachs; all were females and ranged from 32 to 62 centimeters in length. Silver hake, herring, and unidentifiable fish remains were found in 19 of the stomachs. Three stomachs also contained euphausiid shrimps or squid.

Sample 2 was collected in September 1955 at a depth of 60 to 117 fathoms in Georges Basin (lat. 42° 52′ N., long. 66° 53′ W.). Of a total of 116 fish ranging in length from 16 to 47 centimeters, 65 fish, all less than 36 centimeters long, had food in their stomachs. Euphausiid shrimps were the most common item and occurred in 58 stomachs. The only

TABLE 1.—*Stomach contents of fish in four samples of silver hake—expressed as number of stomachs in which item occurred*

Item	Sample 1 August 1954 Provincetown	2 September 1955 Georges Basin	3 October 1956 Point Judith	4 October 1958 Montauk Point
Fork lengths of fish in sample (centimeters)	23.5-62.1	16.0-47.1	18.9-38.1	19.5-46.5
Number of stomachs examined	111	116	80	41
Number with food	20	65	37	31
Percentage containing food	18.0	56.0	46.2	75.6
Food items				
Molluscs	2			
Loligo sp.	2			
Crustaceans	1	58	25	16
Euphausiids	1	58	25	
Decapods				16
Fish	19	7	15	15
Clupea harengus	3			
Merluccius bilinearis	13			1
Stenotomus versicolor			3	
Unidentifiable fish remains	3	7[1]	12	11

[1]Believed to be *M. bilinearis*.

other food was partially digested fish, believed to be silver hake, which occurred in seven stomachs. Eighty-one percent of the males and 54 percent of the females contained food.

Sample 3 was collected in October 1956 southeast of Point Judith, Rhode Island (lat. 41° 18′ N., long. 71° 31′ W.), in 21 to 25 fathoms of water. Of 80 fish ranging in length from 19 to 38 centimeters, 37 fish of all sizes contained food. Euphausiid shrimps were found in 25 stomachs, whereas fish were found in 15 stomachs. In this sample more males (68 percent) than females (43 percent) contained food.

Sample 4 was collected in October 1958 at a depth of 33 fathoms southwest of Montauk Point, New York (lat. 40° 13′ N., long. 72° 18′ W.). The sample consisted of 41 fish with a range of 19 to 46 centimeters in length. A total of 31 fish, representing all sizes, contained food. Decapod shrimps were found in 16 stomachs and fishes, including young-of-the-year silver hake, were found in 15 stomachs. In contrast to samples 2 and 3, more females (83 percent) than males (67 percent) contained food.

The lengths of any identifiable, ingested fishes were measured to determine the sizes of prey fishes the silver hake is capable of devouring. The lengths were recorded to the next lowest whole centimeter and are shown in Table 2. The data are from samples 1 and 3 and represent fishes for which positive identification and length measurements could easily be made. In samples 2 and 4 the ingested fishes were digested beyond positive identification.

In the present study of silver hake stomach contents, Crustacea and fishes were the most frequently found food items. Molluscs and Crustacea, mostly euphausiids, were found in approximately two-thirds of the stomachs of small (15 to 30 centimeters) fish and in more than two-thirds of the stomachs of medium-sized (31 to 45 centimeters) fish. Fish predominated only in the stomachs of large (46 to 60+ centimeters) silver hake. The silver hake is a voracious fish, capable of ingesting large prey fishes. In several instances the stomachs examined contained fishes nearly one-half the length of the predator. It frequently eats other silver hake.

TABLE 2.—*Sizes of fishes ingested by silver hake*

Length of predator (centimeters)	Ingested fishes	
	Length[1] (centimeters)	Species
28.5	6	*Stenotomus versicolor*
28.9	7	do
33.1	6	do
37.7	15	*Merluccius bilinearis*
41.4	13	do
47.6	15	do
49.1	12	do
49.7	25	*Clupea harengus*
50.2	25	*Merluccius bilinearis*
53.6	22	do
57.7	27	do
57.8	27	do
57.9	22	do
58.5	20	do
58.5	13	*Clupea harengus*
62.1	23	*Merluccius bilinearis*

[1]Since digestion quickly destroys fin tissue, accurate fork-length measurements could not be made. Thus the lengths are recorded to the next lowest whole centimeter and may be considered minimal values.

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Furunculosis in Northern Pike

On May 15, 1959, two male northern pike *(Esox lucius)* 27 and 30 inches long were found dead in a spawning pond at Waterville, Minnesota, where they had been placed earlier as brood stock.

An intramuscular abscess measuring 25 millimeters in diameter was found on the smaller of the two fish. Its location was adjacent and posterior to the insertion of the right pectoral fin. The covering of skin and proximal portion of the fin including its articulation were hyperemic and necrotic. A thick serous exudate expressed from the abscess yielded a pure culture of a bacterium morphologically, culturally, and biochemi-

cally indistinguishable from *Aeromonas salmonicida*, the causative agent of furunculosis in salmonid fishes. The same organism could be obtained from the posterior portion of the kidney in both specimens.

The larger northern had a diffuse serosanguineous lesion covering most of the left lateral aspect of the caudal musculature. The skin over this process had lost most of its blood supply, but showed only one small suppurative opening that drained a deeply eroded ulcer in the underlying tissue. *A. salmonicida* was also cultured from this lesion as the predominant organism.

Occasional or experimental infections of warm-water fishes with *A. salmonicida* have been reported in the literature. Williamson (1928) demonstrated that minnows and goldfish *(Carassius auratus)* could be infected experimentally and Plehn (1911) found it in perch *(Perca flavescens)*. The disease is reported to have been found in carp *(Cyprinus carpio)*, sculpins *(Cottus* spp.), and pike *(Esox lucius)* according to the Interim Report of the Furunculosis Committee, Edinburgh, 1930, but it appears that this is the first time that northern pike infected with *A. salmonicida* have been noted in nature in this country.

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Barb-Type Plastic Fish Tag

The Maine Atlantic Sea-Run Salmon Commission and the Inland Fisheries and Game Department need a tag that can be applied to small salmonids for later identification as adults. Atlantic salmon smolts migrate from Maine rivers at total lengths of 5 to 9 inches and return from the ocean in 2 or 3 years at an average weight of 10 pounds. An easily applied plastic barb-type fish tag with some modifications from the description by Yamashita and Waldron (1958) was tested on 73 Eastern brook trout maintained for 6 months in hatchery raceways.

The tag consists of a plastic barbed head four-tenths of an inch in length glued into a piece of plastic tubing 3 inches long (Figure 1). The legend, Me. F. & G. D-1, was printed on the plastic tubing. Tags were furnished by the Floy Tag & Manufacturing Company, Seattle, Washington, and are marketed as the FT-2, small nylon dart and vinyl tubing.

Figure 1.—Plastic fish tag marketed by the Floy Tag & Manufacturing Company as the FT-2, small nylon dart and vinyl tubing (actual size).

All tags were applied about one-eighth to three-sixteenths of an inch to the right of the dorsal fin at an angle so that the barb was forced between the interneurals for firm anchorage. Application was considered best when the tag was firmly anchored and projected dorsoposteriad. The brook trout used in this test were 6 to 9 inches long at the time of tag application.

The first applications of the plastic tags were discontinued after 10 fish had been tagged because it was obvious that the tagging needle (FT-1) was too large and was damaging an unnecessary amount of tissue. The plastic (Natvar) tubing was also too stiff in the cold water and tended to prevent healing of the tagging wound. Natvar is clear, and the printed numbers were difficult to read even prior to application.

Tagged fish were observed to have darkened blotches in the vicinity of the tagging wound, and several of the fish were bleeding. They recovered quickly, however, and were soon feeding and swimming about. There was no observed mortality in the 4 days immediately after tagging, but only one of these fish was recovered at the termination of the experiment. The tag number was illegible, and a half-inch wound surrounded the plastic tubing. The clear plastic tubing used on these first 10 tags was almost impossible to see in the water.

The problems with the applicator needle, the plastic tubing, and the printing were conveyed to the manufacturer who supplied smaller, more carefully machined needles; additional tags with a yellow plastic (resinite EP-2) tubing that remained flexible even

when placed in the freezer; and a printed legend that was easily read. It was our opinion that the 3-inch length of tubing was unnecessarily long; so the tags were shortened to an overall length of 1½ inches. Forty trout were tagged with the new barb tag.

The better applicator needle reduced the tissue damage, although the dark blotches were still obvious dorsally and laterally in the vicinity of the wound. Bleeding was observed as with the initial trial. Tagging was rapid, and following application all fish swam quickly away with no observable signs of distress.

Information was available at the conclusion of the 6-month test period on 28 of the 40 trout tagged with the yellow plastic tags. Seven trout were known to have died in the hatchery raceway, and of the remaining 21, only 6 could be identified by tag number. The numbers and letters on the other 15 tags had disappeared or become so faded that they were illegible. Ten of the final 21 survivors had an open, necrotic wound around the plastic tubing from one-eighth to one-quarter inch in diameter, but the other 11 tagging wounds had healed. All of the survivors, regardless of the condition of the tagging wound, were in excellent condition and had experienced acceptable growth.

The junior author made an effort to solve the problem of the tagging wound by using the same barb with a short length of monofilament replacing the plastic tubing. A small monel metal dangler was attached to the monofilament for identification. All of the 23 trout used to test this tag had open necrotic wounds around the monofilament. The danglers also tended to gather debris and were easily torn loose during routine handling. No further work is planned with the monofilament-type barb tag.

It was concluded that: (1) the barb-type plastic tag can be applied easily and quickly; (2) a more durable ink is needed for printing on the plastic tubing if the legend is to remain exposed; (3) the tag as presently made could be used for short-term experiments, since there seem to be no immediate effects such as tagging mortality or loss of tags; and (4) the tag is worth further development and testing.

The tag manufacturer was very cooperative and anxious to receive suggestions for the improvement of his tags. The authors would welcome correspondence from other fishery scientists who have had experience in the use of the barb-type plastic tags in small fish or who would like additional information about the present work.

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REVIEWS

Oceanography and Marine Biology, A Book of Techniques. *By H. Barnes. George Allen and Unwin Ltd., London. 1959. 218 pp., illus. 35s.*

The world beneath the ocean surface is remarkably inaccessible to direct observation by men. In consequence, marine scientists have had, perforce, to develop apparatus for studying indirectly the waters of the ocean and their contents. During the last few decades, especially, physical and chemical oceanographers, geologists, biologists, and fishery scientists have brought forward a vast array of new equipment and ingenious techniques. A comprehensive description of this equipment and methodology would be extremely useful, both as a text for students and a reference work for researchers. Unfortunately, this small volume meets this need only to a minor degree.

Dr. Barnes' book contains four brief chapters. Under *Sampling of the Living Organisms* he describes some of the apparatus and methods of collecting and measuring bacteria, nannoplankton, and diatoms in water samples, provides a brief discussion of plankton nets and pumps, and gives a rather detailed discussion of the construction and use of the Hardy plankton recorder and related apparatus. There are also descriptions of various types of trawls, dredges, and bottom "grab" samplers, together with description of coring devices, both gravity and piston-types. This, except for the subsequent material on bottom photography, is the only mention of the equipment and techniques of submarine geology; there is no mention of magnetometers or gravimeters, nor of the techniques of seismic research.

The chapter on *Use of Sound Waves* describes the principles of echo sounders, illustrates their use in commercial fishing and fisheries research, and discusses briefly studies of the deep scattering layers. A short section is devoted to underwater sounds of biological origin.

The chapter on *Some Properties of the Water Itself* describes the classical apparatus for measuring temperatures and for taking water samples: bucket thermometers, the Lumby surface sampler, insulated and reversing water bottles, reversing thermometers, the Mosby thermosound, and the Spilhaus bathythermograph (which is called a "new" instrument, although it has been in wide use for over a decade) and the related sea-sampler. Resistance thermometers, thermistors, and conductivity cells are dealt with in two sentences. Current measurements are discussed under two headings—drift methods and flow methods. Under the former are discussed various kinds of drift bottles and drift cards, and tracking of buoys. Under flow methods are described various impeller-type current meters, such as those of Ekman, Carruthers, and Von Arx, the Jacobsen current drogue, and the geomagnetic electrokinetograph. There is no mention of apparatus and techniques of the study of waves and swell, of turbulence and diffusion, nor of light in the sea.

A final chapter on *Photography and Television* includes an excellent description of the application of aerial photographic methods to beach profiles and determination of near-shore water depths, a good description of some underwater camera equipment, and an illuminating discussion of underwater television apparatus.

This book will be of interest to general readers and of value, as an introduction to oceanographic and marine-biological methods, to students of oceanography and fisheries. The author apparently did not intend it to be a comprehensive reference work for research oceanographers, despite the jacket blurb, since he is also preparing a more comprehensive treatise on *Apparatus and Methods of Oceanography*, of which *Part One: Chemical* was also published during 1959 by Interscience Publishers, New York.

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Rainbow Trout in Mexico and California, With Notes on the Cutthroat Series. *By Paul R. Needham and Richard Gard. (University of California Publications in Zoology, Vol. 67, No. 1, pp. 1-124, 8 plates, 40 figs., 3 maps). University of California Press, Berkeley, Calif. 1959. $2.50.*

There has been controversy for years concerning the taxonomy of the rainbows, and this is a timely attempt to clarify the situation. Owing to the extinction of some races and numerous widely-scattered hatchery plants, it is perhaps too late to ever know what many of the original stocks were. This same obstacle undoubtedly made it nigh impossible to obtain large samples of native fish.

This paper utilizes 12 meristic counts and 28 body proportions in comparing populations of trout designated as rainbows taken from Eagle Lake in northern California to the Rio del Presidio in Sonora, Mexico. Nevertheless, we regard this paper as qualitative owing to the paucity of material—306 specimens from 17 localities, or an average of 18 per locality, actually ranging from 2 to 30 fish per locality, collected over 30 years, and extending over 1,000 miles of territory. This same paucity of material is evident in Table 4 giving water temperatures in Mexican localities. Fifteen water temperatures taken during 5 months in two different summers and accompanied by only eight air temperatures, are scarcely worth recording.

The statistical methods employed may not be efficient. Regression analysis of body proportions was omitted, the "*thousandths* of standard length" being treated in a manner similar to meristic counts, despite the very small sample numbers, the considerable variation in fish size, and no evidence that the plots of standard length and the various measurements pass through the origin and are linear throughout the length range.

The authors assumed that the populations are all "rainbows," but on page 47 they mention the faint yellowish "cutthroat" mark of the trout from the Rio Yaqui in Sonora, Mexico, which de Buen in 1947 classified as Rio Grande cutthroats. Again on page 51 they say of the trout they style the Mexican golden trout, "These are beautiful fish and their dominant feature, when alive, is the bright orange 'cutthroat' color below the jaw and on the belly."

It is well known that cutthroats often have the colored lateral band and I have observed the "strong orange of the lower fins" (page 57) and the rosy color which they quote from Flechsig's field notes, "orange-red of ventrum does not extend up above lower bases of the paired fins. Rosy color is well developed between the parr marks," on cutthroats but never on rainbows. This exemplifies the difficulty of working with old preserved material when the principal identifying character is a genetic color pattern. This is also evident from the authors' color descriptions as "badly faded," page 59; the Rio Culiacán collection "closely resemble the Sinaloa rainbows after preservation," page 57; "these 8 specimens have faded to a dull brown . . . the rainbow stripe has completely disappeared," page 36.

A few contradictions are curious. On page 45 the authors (after not worrying about the underjaw "cutthroat" coloring) are upset by finding one specimen (out of 25) in the Santo Domingo River, Baja California, with three *well-developed* basibranchial teeth. They say, ". . . it gave no hint of other cutthroat characteristics. Hybridization with sea-run cutthroat could have occurred earlier, and this fish could represent the result of a rare recombination of genes or a gene mutation suddenly producing this character." After calling the Rio Yaqui trout "rainbows" on page 47, they state on page 64 that, "The possession of a faint, yellowish 'cutthroat' mark by the Black Canyon and Casas Grandes rainbows could reflect hybridization with the Rio Grande cutthroat . . ."

On page 59 the authors conclude that Stilwell was misinformed concerning the planting of hatchery rainbows in the Rio Truchas, but on page 64 the authors say, "If it is true, as Stilwell (1948, p. 135) states, that English immigrants introduced rainbow trout into northwestern Mexico, the Black Canyon and Casas Grande populations could represent hybrids not only between the Rio Grande cutthroat, but also between the Gila trout or some other form of rainbow."

The "coefficient of difference" used by the authors is a "cookbook" method devised to replace standard statistical procedures. According to this method the vertebral counts of localities are compared (p. 34) in which even the extreme ranges of the counts do not overlap and yet they cannot decide whether or not the two populations overlap!

The authors prefer to ignore the present nomenclatorial procedure of dropping the extra *i* in the genitive case of proper names denoting species.

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Handbook of Computations for Biological Statistics of Fish Populations. *By William E. Ricker. (Fisheries Research Board of Canada, Bulletin No. 119). The Queen's Printer, Ottawa. 1958. 300 pp., 44 figs. $5.00.*

This is a revised and greatly enlarged outgrowth of the author's earlier work, *Methods of Estimating Vital Statistics of Fish Populations* (1948), affectionately known by fishery workers everywhere as "The Green Monster." The revision presents a wealth of measurement theory and technique, the enormity of which defies comprehensive review. Compiled by one of the world's leaders in the field of population dynamics, the contents touch upon all problems commonly encountered in estimating fish population parameters. A wide variety of worked examples using hypothetical and actual data facilitates the application and solution of formulas derived by the author or drawn from a vast but scattered literature. Sources of estimation bias are recognized and, where possible, accounted for through appropriate data adjustment.

This is not a textbook, but strictly a handbook as the title indicates, and it will prove most useful to the more advanced student or researcher. The user must be familiar with the vagaries of natural populations, the intricacies of sampling theory, and the nature of variability. A working knowledge of the structure of modern fishing theory is also implied. Such previous understanding is indeed a formidable barrier to most biologists and the lack of it is frequently circumvented through acceptance at face value of measurement techniques that may not be appropriate in given situations. Unfortunately, the author did not devote more space to developing, in elementary terms, the theory referred to above. For the average biologist this would have meant enhancement of the book's over-all value and, conceivably, curtailment of indiscriminate "cookbook" application of techniques. Instead, the author plunges abruptly into a glossary of complex terms and symbols, many of which have been shown to have highly ambiguous meanings. [Note: An attempt to standardize terms and symbols has been made by the Conseil Permanent International pour l'Exploration de la Mer (1959).] Following a rather brief discussion of parameters (*i.e.*, mortality, growth, and reproduction), he then considers in relatively great detail the interpretation and use of "catch curves" in estimating survival, and hence total mortality, in *defined* populations. Much of this discussion relies upon hypothetical examples in which certain factors, particularly recruitment, are either fixed or allowed to vary. This conditional approach illustrates what theoretically happens in nature; but is of little aid to the biologist struggling to estimate, say, actual recruitment, and hence recruitment-yield-stock relationships. The point here is that too much emphasis is frequently placed on the hypothetical mechanics of accepted and well-documented theory, and not enough on the real problems of establishing the conditions necessary to implement the theory and, just as important, of acquiring the data for computing the statistics it is designed to yield.

Chapters on mark-recovery experiments; uses of catch statistics to assess populations and various characteristics thereof; yield prediction; stock-progeny relationships; and the concept of equilibrium yield complete the handbook. Those describing

the purpose, structure, and application of marking experiments are particularly well done and should receive considerable attention from fishery biologists everywhere. The section on stock-recruitment relationships is greatly augmented by the author's own important contributions in this area. A very comprehensive bibliography and useful index supplement the text.

Seemingly glossed over throughout the book is consideration of the real adequacy of various types of fishing gear as sampling devices. In this connection one must acknowledge the important concept of "effective fishing intensity" advanced by Beverton and Holt [*On the Dynamics of Exploited Fish Populations* (1957)]. They have shown through spatial and temporal stratification of fishing effort that a true probability-of-capture index can be derived for bottom-dwelling species taken by trawls. But this should not divert our attention from the fact that the effectiveness of other gears such as traps, gill nets, long lines, etc., depends almost entirely on the fluctuating availability of the species they are designed to capture. Population statistics based on catch and effort data issuing from fisheries employing such gear thereby suffer from bias of unknown degree.

In addition to presenting a concise summary of available techniques for studying fish populations, this handbook also alludes to many areas of fishery science in which knowledge is weak or lacking. In a sense, it could be considered a stimulus to further research in the field of population dynamics. A bargain at twice the cost, it will prove indispensable to many practicing biologists.

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ON THE DYNAMICS OF EXPLOITED FISH POPULATIONS. *By R. J. H. Beverton and S. J. Holt. (Great Britain Ministry of Agriculture, Fisheries and Food. Fishery Investigations, Series II, Volume 19). London. 1957. 533 pp., figs., tables. £6 6s.*

To say that this is a monumental work and is destined to become a classic in its field may sound trite, but in my opinion is a simple statement of fact. No treatise, on this subject, of comparable scale existed previously or is likely to be forthcoming for some years. I was privileged to hear parts of the formulations ably presented by the senior author in a special course of the Duke University Marine Laboratory at Beaufort, North Carolina, in the summer of 1951. The completed volume reflects the same thoroughness of analysis and care in presentation that was evident during the course. It represents the fruits of 6 years' work on the part of the authors, both internationally distinguished as biologists and biometricians. The analyses are directed primarily toward demersal fish and fisheries of the North Sea, but will inevitably be of much wider application in other fisheries and to other groups of animals as well.

The reader will find the arrangement of the material both orderly and logical. Part I introduces the concepts of factors contributing to the increase or decrease of fish populations. This is followed by the presentation of mathematical models which take into account the four major influences on population size: recruitment, growth, natural mortality, and fishing mortality. These models are "deterministic" in that they assign constant values to population parameters. Although "probabilistic" models (with statistical variation in parameters) would be closer to nature, the authors have concluded (and I believe rightly so) that these models would not justify the great labor involved and the further complication of an already complex set of formulae, in consideration of the limitations of the basic data. The section concludes with formulae for estimation of the all-important yield, and other parameters such as catch-per-unit-effort, population number, mean length, and mean weight. Notable in this section is the use of the growth formula of von Bertalanffy, which the authors believe to have a much sounder physiological basis than the empirical curves used in previous treatments.

The problem of variation in the four basic parameters is considered in Part II. Here these rates are related to age, time, and population density. The further complexities introduced by fisheries depending on mixed populations of two or more species are also analyzed.

Estimation of the vital rates and other numerical values included in the mathematical models is set forth in Part III. Illustrative material is drawn mainly from the plaice and haddock fisheries of the North Sea, although other species and areas are mentioned. Total mortality rate and maximum age are derived, after which the problem of separating natural and fishing mortalities is faced. Methods of this separation from either marking experiments or age composition data are amply described. Methods of deriving recruitment and growth rates complete this section of the book.

A most salient feature, from the standpoint of the fishery administrator, is found in Part IV, which shows in detail how to apply the formulations to problems of regulation. Even an example of a work sheet for the calculations is provided. Calculations result in the yield curves and "yield isopleths." There is an extended exposition of certain principles and methods of fishery regulation, which, although slanted toward trawl fisheries, have a much wider application. Novelties, as compared with most studies of this type, are the consideration of economic as well as biological relationships, and the proposal of control charts to evaluate the effects of regulations. In the final pages this section becomes rather specific to North Sea problems, showing the effect of several fisheries working on the same resource, and venturing a prediction of the benefits to be achieved by the adoption of specific regulations.

To complete the book, the authors have added appendices containing tables of data used in application of the models, an extensive bibliography, and a useful glossary of symbols and subject index.

The reviewer had difficulty finding anything in this excellent book to criticize. However, for many present-day fishery workers the very thoroughness and complexity of the formulations, which provide one of the strengths of the treatment, also may contain one of its weaknesses. Men responsible for fishery administration are often not highly trained mathe-

matically. Such men are likely to be taken aback by, and perhaps even to distrust, such complex derivations as those found, for example, on page 143.

The authors recognize limits beyond which formulations cannot be profitably carried in representing nature, when they say (page 80), "It so happens that only a few simple functions $F_{(t)}$ can be introduced into the theoretical models we have developed without resulting in undue mathematical complexity, . . ." Although by no means displacing the theoretical approach, the laboratory and field experiment, with summation of all the complex interacting influences which affect population size and yield, can serve as valuable supplements and verification, and its meaning will be readily grasped by the average fishery biologist.

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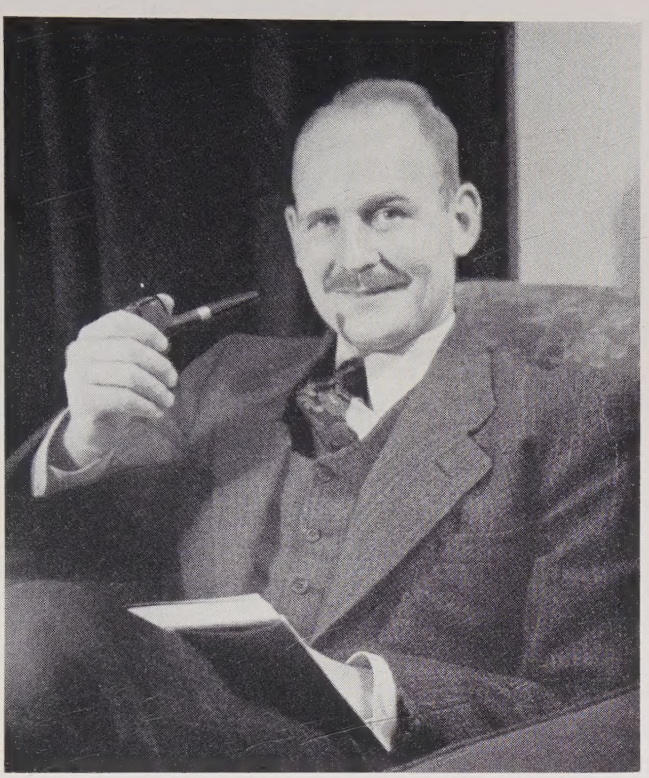

Richard Birnie Miller
1915-1959

The death of Richard B. Miller on February 23, 1959, at the height of his career deprived the fishery profession of one of its most distinguished North American members. His contributions to the field of fresh-water fishery problems were highlighted by his work on *Triaenophorus*, a fish parasite which has had major economic significance to commercial fisheries, and by his critical appraisals of the role of hatchery-reared fish in population management. These latter studies, which dealt with whitefish and trout, gained for him the confidence of administrators who made possible experimental management programs that added significantly to our knowledge of population dynamics. His studies of hatchery-reared trout in streams showed that they did not compete well with wild fish. With keen insight he sought the reasons in the areas of physiology and behavior. Dr. Miller was more successful than many of his colleagues in bridging the gap between rigorous scientific investigations and the practical problems of fishery management.

Dr. Miller was born on March 29, 1915, in Weyburn, Saskatchewan. After completing his primary and secondary education in Saskatchewan, he entered the Honour Biology Course at the University of Toronto and graduated in 1936 with the G. A. Cox gold medal. He earned his master's degree in 1937 and his doctorate degree in 1939 from the University of Toronto. In 1939 he became a lecturer in zoology at the University of Alberta, advanced to professor in 1952, and head of the department in 1956.

Dr. Miller was active in fishery and academic organizational work throughout his professional career. He was a member of the National Research Council of Canada from 1956 and the Research Board of Canada from 1957 until his death. In 1957 he served as vice-president of the Wildlife Society and in 1959 was elected to fellowship in the Royal Society of Canada. The professional societies with which he was affiliated were the American Fisheries Society, Wildlife Society, American Society of Limnology and Oceanography, Society of Systematic Zoologists, International Association of Limnology, New York Academy of Science, and the Arctic Institute of North America.